COLLABORATIVE LOGISTICS AND TRANSPORTATION NETWORKS

A MODELING APPROACH TO HUB NETWORK DESIGN

BAS GROOTHEDDE

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Preface

This dissertation is the accumulation of five years of research and projects at TNO and the Delft University of Technology and focuses on the design of logistics networks. The underlying question was how to design these networks in which the actors collaborate and still make sure the network solution complies to the service requirements. By taking into account not only the costs for transportation, inventory, and warehousing, but also the costs associated with transactions more feasible network solutions can be found. The pain of switching between alternatives, partners and networks is included. Incorporating the transaction costs and additional resistances actors might have, can influence the outcome of the network design significantly and can therefore have great impact on the feasibility of the network solution. It was during several key projects conducted at TNO that the notion was formed that, when trying to implement these networks, optimization of the networks was not enough.

Conducting the research and writing this dissertation was quite an endeavor and gave me the opportunity to work closely with some of the major companies in the Netherlands, to work in a great team of colleagues at TNO, and visit the Massachusetts Institute of Technology. All in all it took more than five years, stressful at times, but I enjoyed it greatly. This is of course closely correlated to the persons who surrounded me during this five-year period and made it possible for me to conduct the research and write this dissertation. First and foremost, I would like to thank Frank Sanders who gave me the opportunity to start this project, supported me throughout this journey and with his ideas got me on the right track.

Next, I am very grateful to Jos Vermunt who taught me the basics of logistics and inspired me through his enthusiasm, energy and ideas. It goes without saying that during the Distrivaart project, the case study that is presented in this dissertation, he played an indispensable role; from the initial idea of a collaborative network, through extensive research, to the final implementation of the concept. I would like to thank Lóri Tavasszy who convinced me to proceed and simply start writing. Perhaps, without knowing it, he gave me this crucial advice. Next, of course, I would like to thank Piet Bovy, who gave me, with the opportunity to finish my dissertation and through his guidance and excellent input, the decisive push. His invaluable comments, suggestions, and remarks improved the dissertation enormously. During my short but pleasant stay at the department of Transport and Planning of the Faculty of Civil Engineering and Geosciences I was warmly welcomed and provided with an excellent working environment.

Finally, I would like to thank Cees Ruijgrok, without whom I would never have started and finished this journey. Most importantly he gave me valuable comments, ideas and feedback. Cees had a hand in virtually every major breakthrough and innovation presented in this dissertation. Next to his scientific input I commend the discussions we had over the issues raised in this dissertation, the guidance he provided, and thank him for leveling the path from beginning to the end.

Various other persons have also helped me shape the dissertation in its current form. I thank Roland van der Klauw for his effort at the start of my research and facilitating my stay at MIT in Boston Massachusetts and Arie Bleijenberg and Ben Jansen for giving me the possibility to finalize this dissertation. Special thanks go to Bart Kuipers, Mirjam Iding, Art van Dongen, Menno Rustenburg, Egbert Guis, and Justus Becker for invaluable work during the Distrivaart project. I would like to thank the people of the Holland International Distribution Council,

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I am grateful for the great team of colleagues at TNO, business unit Mobility and Transport for generating such a pleasant and vibrant working atmosphere, allowing me to participate in inspiring projects, developing new concepts and technologies, implementing logistics networks, and still allowing me to work on my dissertation. I am very grateful and very well aware that these working conditions are virtually unique.

Finally there is a group of people who formed the home front during the entire production process of my dissertation. I am very much indebted to the Groothedde's in Zierikzee, for educating me, stimulating me, and providing me with a warm and lovely home. It was my mother who taught me the basics of logistics through the concept "*never return to the kitchen empty-handed*", undoubtedly the key concept in today's logistics. The fascination with hub and spoke networks was encouraged by my father making me repair my own bike. I also would like to thank Miranda, Jeffrey and Thomas, Tineke and Arie. Without doubt however, Hanneke must receive the most gratitude and I can not thank her enough. Putting up with my writing activities was no sinecure and I am very well aware that I have to make up for all the time I have spent behind my little desk. Thank you for your encouragement, distractions, and reminding me, at times when I needed it most, what the really important things in life were. But most of all I would like to thank you for being there and providing a home for me and our lovely little daughter Elsje.

Bas Groothedde Delft, November 2005

TABLE OF CONTENTS

Glossary of logistics symbols

The glossary below gives the description of the logistics symbols used in this thesis. The symbols represent either an object like a facility (warehouse, production site or transshipment point) in a logistics network, an activity, or an actor within the logistics network. In this thesis, the terms *warehouse* and *distribution center* may be used interchangeably. In traditional logistics terms, the major function of the warehouse is storage; the major functions of the distribution center are consolidation, mixing, repackaging and distribution to the customer. This distinction between a warehouse and distribution center is not made however in this thesis. Throughout this thesis we will make use of different types of linkages and interactions between the different actors and object in the logistics network. However, we do not specify these line types individually here, as they are used to denote different interactions and linkages throughout this dissertation. We will do so whenever they are used in a figure or schedule.

M	Manufacturer, decides on the location and nature of the production process and price of the product.		Potential (hub) location.		This symbol represents a transshipment center.
R	Represents a retailer, usually at the end of the logistics network.		Generic symbol used to denote a node in the network, often an origin or destination node.		This symbol represent a multimodal transshipment center.
L	Logistics service provider (LSP), a third party operator that organizes logistics activities.		Symbol representing a destination node in the logistics network.		Channel in the service network.
T	Terminal operator, organizes the transshipment of products between modes.		Location in the network where crossdocking takes place.		Scope of the collaboration.
I	This symbol denotes an Inland shipping carrier.		Warehouse with cross-docking activity.		Efficient boundary of the firm.
C	Consumers, that can decide on the nature and the volume of goods to purchase.		Rolling stock/or pipeline stock.		Unloading a vehicle.
R	This symbol denotes a producer of raw materials used for further processing.		Triangle that represents a stock location in the network.		Loading a vehicle.
S	Suppliers, starting point of the logistics network. They produce and deliver the supplies/intermediate products.	R	Filled symbol indicates a dominant actor in the logistics network.	A ◁ B	Dominance of actor B over A.
Ca	Symbol representing a carrier usually a trucking company.	D	Distribution centre.	A ○ B	Indepence between actor B and actor A.
	This symbol represents a hub node in the logistics network.		This symbol represents a warehouse location of a LSP.	A = B	Interdepence between actor B and actor A.

Glossary of mathematical symbols

Before getting started some remarks about the notation need to be made. Equations, tables and figures will be numbered (*a.b*), where '*a*' is the chapter number and '*b*' the equation, table or figure number. Footnotes in the text are indicated with a superscripted number and placed on the bottom of the same page. Notes and remarks in figures and tables are numbered using the roman numerical system. Also, an attempt is made to use as consistent a set of mathematical symbols throughout the dissertation as possible. Capitals denote criterion variables (totals) and the decision variables are denoted by the reserved capitals (*X, Y*, and *Z*). Parameters are denoted by Greek lowercase letters. Superscripts are used to denote the type of variable; the subscript is always used to denote the index. For example, the superscript in C_k^{whl} denotes warehousing labor; the subscript denotes hub *k*.

B	The sum of the total payments between actors (€).
ΔB	Additional payments incurred due to opportunism (€/transaction).
C	Total logistics costs of the network solution (€).
ΔC	Total comparative costs of a market solution or hierarchy solution (€).
C^*	Optimal total logistics cost of network solution (€).
C_{ij}	Total logistics cost on origin-destination relation $i \to j$ (€).
$C_{ij,b}$	Total cost of shipments of product *b*, on $i \to j$ (€/year).
$C_{s,l1}$	Total costs of inner-loop l1 of sequence *s* (€).
C^{csl}	Annual labor costs/FTE searching information (€/FTE/year).
C_k^{hl}	Total fixed annual labor costs for handling at *k* (€/year).
C^{is}	Total investment in information system (€/year).
C^{isl}	Annual labor costs for order administration (€/year).
C_k^{hf}	Total annual fixed costs for handling equipment at *k* (€/year).
C_k^{whf}	Total fixed annual costs for warehousing at hub *k* (€/year).
C_k^{whh}	Total annual fixed costs incurred for handling equipment at *k* (€/year).
C_k^{whl}	Total fixed annual labor costs for warehousing at *k* (€/year).
D	Total annual demand on all origin-destination relations (items/year).
D_i	Total annual demand originating at origin node *i* (items/year).
F_k	Total fixed costs associated with opening a hub at node *k* (€).
FTE	Denotes the number of full-time-equivalents required (FTE).
G	Total governance costs of a network solution (€).
ΔG	Total comparative governance costs, market or hierarchy solution (€).
ΔG_0	Total comparative governance costs with no asset specificity (€).
H_s	Total available operational hours on sequence s (hours/year).
H_1	The interval (or headway) between the first two dispatches (time units).
H^{max}	The maximum interval (or headway) between successive dispatches.
H_k^h	Total operational hours handling equipment on hub *k* (hours/year).
L	Used to denote the Length of the *Markov Chain* (number of iterations).
ΔM	Total potential savings matrix on all origin-destinations (€).
O	Total number of orders per year (orders/year).
P	Total production costs of an alternative (€).
ΔP	Total comparative production costs, market or hierarchy solution (€).
P'	Production volume rate at manufacturer (units/time unit).
Q	Homogenous population of actors or items.

Q_k	Annual throughput in units at *k* (items/year).
$Q_{k,s}^{in}$	Total annual inbound of sequence *s*, at hub *k* (units /year).
$Q_{k,s}^{out}$	Total annual outbound of sequence *s*, at hub *k* (units /year).
S	Used to denote the current network solution.
S_0	Initial network solution of network optimization procedure.
T_s	Total shipment time using sequence *s* (time units).
V	The total number of shipments in a sequence of dispatches.
X_{ij}	Decision variable that denotes the fraction of flow shipped via *ij*.
$X_{ij,b}$	Fraction of the total flow on *ij* of product *b*, shipped itinerary *f*.
X_{ijkl}	Decision variable, denotes the fraction of flow shipped via *ijkl*.
X_{ilj}	Flow between hub *i* and hub *j* originating at origin *i*.
Y_{ikl}	Flow between hub *k* and *l* that originates at origin *i*.
Y_k	Decision variable, $Y_k = 1$ if a hub is located at node *k*, $Y_k = 0$ otherwise.
Y_{ik}	Decision variable, $Y_{ik} = 1$ if demand at node *i* is assigned to facility *k*.
Z_s	Decision variable $Z_s = 1$ if sequence s is present in the network solution.
Z_{ik}	Fraction of total flow on relation from origin *i* to hub *k*.
a	Index of the segments of network sequence *s*.
b	Index of the commodity or product type.
c	Index of the set of customers in the network.
$\overline{c}$	Average costs per unit for shipping a single unit (€/unit).
c_{ij}	Costs of shipping a unit from origin *i* to destination *j* (€/unit).
c^{adm}	Administration costs per unit (€/unit).
c^{bc}	Bargaining costs when switching, transaction costs $\delta_i^{tc\mathrm{I}}$ (€).
c^{bl}	Cost incurred for a unit in backlog (€/unit).
$\overline{c}_1^c$	Average shipment cost of consortium participants in network 1 (€/unit).
$\overline{c}_2^c$	Average shipment cost of consortium participants in network 2 (€/unit).
c^{csf}	Search costs fees, out-of-pocket costs when switching, part of $\delta_i^{tc\mathrm{I}}$ (€).
c^{ec}	Enforcement costs incurred, transaction costs $\delta_i^{tc\mathrm{I}}$ (€).
c^f	Fixed cost per shipment (€/shipment).
c_s^f	Fixed cost/time unit using sequence *s* (€/time unit).
c^h	Warehousing and inventory costs per unit-hour (€/unit/hour).
c_k^h	Handling costs at origin hub *k* (€/unit).
c_l^h	Handling costs at destination hub *l* (€/unit).
c_k^{hf}	Fixed costs incurred for handling at hub *k* (€/unit).
c_s^{hub}	Shipment costs/unit of hub network shipments using sequence *s* (€/unit).
c^{hv}	Variable costs incurred for handling activities per unit (€/unit).
c^{inv}	Incurred inventory costs per unit (€/unit).
c^l	The cost attributable to each incremental vehicle kilometer.
c^{leg}	Legal costs induced due to opportunism, part of $\delta_i^{tc\mathrm{II}}$ (€).
c^{ord}	Costs incurred for placing an order (€/order).
$\dot{c}^s$	Represents the added cost of carrying an extra unit.
c^s	The cost attributable to each trip, regardless of distance.
c^{set}	Fixed setup costs incurred per individual per item (€/unit).
c^{sc}	Search costs as a part of the transaction costs $\delta_i^{tc\mathrm{I}}$ (€).
c^{tf}	Fixed costs of truck transportation per unit (€/unit).
c^{tv}	Variable costs of truck transport per unit (€/time unit/unit).
c_s^{trh}	Inter-hub transfer costs per item (€/unit).
c^u	The handling cost per shipment (€/shipment).

c^v	Variable cost incurred per shipment (€/shipment).
c^{wh}	Incurred warehousing costs per unit (€/unit).
$d_{a,s}$	Number of units on segment *a* of sequence *s*.
$f^l(\Delta Q)$	Value loss function when opportunism arises.
h	Index used to denote the itinerary present in the network.
i	Index used to denote the origin-node number.
j	Index used to denote the destination-node.
k	Index used to denote the origin hub-node.
l	Index used to denote the destination hub-node.
l_{ij}	distance in kilometers on origin destination
$l1$	Inner-loop 1, iteration counter of utilization calculation.
$l2$	Inner-loop 2, iteration counter of the transaction cost calculation.
$l3$	Outer-loop iteration-counter of Simulated Annealing procedure.
Δm_{ij}	Potential savings on origin-destination relation $i \to j$ (€).
o	Index to denote the number of vehicles deployed.
p	Number of facilities to be located *p*-median problems or *p*-hub problems.[1]
q	Index to denote the number of customers in consortium.
$\overline{q}$	Average size of the replenishment order in number of units (units).
q^*	Optimal size of the replenishment order (units /order).
r	The reorder point in number of units (units).
r^*	The derived optimal reorder point in number of units (units).
s	Denotes sequence s in the hub network.
t	Denotes a time period or specific point in time Z (time units).
t^m	Shipment time between origin and destination (time units).
t^w	Total waiting time between successive dispatches (time units).
u	Index that denotes the loading unit (e.g. pallets, boxes, etc.).
us	Index that denotes the different transaction costs categories.

[1]) In hub network literature *p* is often used to denote the number of hubs to be located.

Key parameters

In an effort to construct a consistent set of parameters we listed the key parameters below. However, in the list above there are some cost-parameters included (especially those related to costs). We have chosen to depict these in the alphabetical sorted list above to provide the reader with a logical overview of mathematical symbols.

α	The temperature reduction parameter in the linear SA cooling schedule.
α_s	Discount factor for inter-hub transfer rate (-).
β_0	Reduction factor of the initial temperature.
χ_k	Capacity of transshipment equipment deployed on *k* (units/time unit).
δ_i^{tc}	Transaction costs of participant *i* costs (flow originating at *i)* (€/transaction).
$\delta_{n,u}^{tc}$	Transaction costs of category *u* of network solution *n* (€/transaction).
δ_1^{tc}	Transaction costs of network solution 1 (€/transaction).
$\delta_i^{tc\mathrm{I}}$	First round information costs of participant *i* (€/transaction).
$\delta_i^{tc\mathrm{II}}$	Second round transaction costs of participant *I* (€/transaction).
$v_{\max}$	Capacity of vehicle in number of units (units/shipment).
v^{hub}	Shipment size in units of hub-network shipment (units /shipment).
v_{max}^{hub}	Maximum shipment size of hub-network shipment (units/shipment).
v^t	Shipment size in units of truck transportation (units/shipment).
$v_{\max}^u$	Maximum capacity of a loading unit (pallet).

ϕ_s	Capacity deployed on sequence s (units/time unit).	θ	Fraction of the flow shipped with direct road transport (%).
φ_n	Asset specificity, where index n indicates the network solution (€).	ρ	Inventory carrying charge, (% of value/time unit).
γ	Current interest rate as a percentage of value (% of value/time unit).	σ	Denotes the standard deviation of demand.
η_k^h	Capacity of handling equipment deployed at hub k (units/hour).	τ	Denotes the temperatures used in the simulated annealing procedure.
κ	Boltzmann's constant, indicates temperature - kinetic energy relation.	τ_0	Initial temperature of the cooling schedule.
λ_s	Frequency of service s (trips/time unit).	τ_f	Final temperature of the cooling schedule.
μ_s	Utilization of the equipment deployed on sequence s.	$\bar{\varpi}$	The average number of units in an individual order (units/order).
μ_k^h	Utilization of the equipment and labor costs at hub k.	ξ	Random generated number, $(0 < \xi < 1)$ uniformly distributed.
ν	The shipment size on an origin-destination (units/shipment).	ζ_s	Predefined stop criterion of inner-loop $l1$.
$\bar{\nu}$	The average shipment size (units/shipment).	Prob^t	The probability of stock-out occurring during period t.
ν^*	Optimal shipment size on origin-destination (units/shipment).	Prob^{ac}	Acceptance probability of network solution.
ν_{max}^t	Capacity of vehicles deployed in truck transportation (units/shipment).	ϵ^s	Additional resistance to participate (€/transaction).
π	Average value product shipped (€/m^3).	ϵ_i^s	Additional resistance to participate of participant i (€/transaction).

Sets

$\mathcal{A}$	The set of segments on the hub-network sequences.	$\mathcal{N}$	The set of network solutions indexed $\mathcal{N} = (1,...,n,,...,\lvert\mathcal{N}\rvert)$.
$\mathcal{B}$	The number of product types or indexed $\mathcal{B} = (1,...,b,...,\lvert\mathcal{B}\rvert)$.	$\mathcal{O}$	Set of identical vehicles in the fleet, indexed $\mathcal{O} = (1,...,o,...,\lvert\mathcal{O}\rvert)$.
$\mathcal{C}$	The set of customers in the network, $\mathcal{C} = (1,...,c,...,\lvert\mathcal{C}\rvert)$.	$\mathcal{P}$	The set of the (potential) participants in the consortium $\mathcal{P}= (1,..., p,...,\lvert\mathcal{P}\rvert)$.
$\mathcal{E}$	The set of links representing the connections between the nodes $\mathcal{V}$.	$\mathcal{P}_1$	Number of participants in consortium in network solution 1.
$\mathcal{G}$	Representation of the physical network, nodes $\mathcal{V}$, and links $\mathcal{E}$.	$\mathcal{S}$	The set of services on the service network. $\mathcal{S} = (1,...,s,...,\lvert\mathcal{S}\rvert)$.
$\mathcal{H}$	Set of itineraries present in the service network, indexed $\mathcal{H} = (1,...,h,...,\lvert\mathcal{H}\rvert)$.	$\mathcal{T}$	Set of temperatures in the cooling schedule, $\mathcal{T} = (\tau_0,\tau_1,..,\tau_f)$.
$\mathcal{I}$	The set of origin-nodes indexed $\mathcal{I} = (1,...,i,,...,\lvert\mathcal{I}\rvert)$.	$\mathcal{W}$	The set of origin-destination relations, indexed $\mathcal{W} = (1,...,w,...,\lvert\mathcal{W}\rvert)$.
$\mathcal{J}$	The set of destination-nodes indexed $\mathcal{J} = (1,..., j,...,\lvert\mathcal{J}\rvert)$.	$\mathcal{U}_1$	Set of transaction cost categories indexed $\mathcal{U}_1 = (1,...,us,...,\lvert\mathcal{U}_1\rvert)$.
$\mathcal{K}$	The set of origin hub-nodes indexed $\mathcal{K} = (1,...,k,...,\lvert\mathcal{K}\rvert)$.	$\mathcal{U}_2$	Set of transaction cost categories indexed $\mathcal{U}_2 = (1,...,u,...,\lvert\mathcal{U}_2\rvert)$.
$\mathcal{L}$	The set of origin hub-nodes indexed $\mathcal{L} = (1,...,l,...,\lvert\mathcal{L}\rvert)$.	$\mathcal{V}$	The set of nodes in the network indexed $\mathcal{V} = (1,...,v,...,\lvert\mathcal{V}\rvert)$.

Glossary of terms

The glossary of terms below provides a brief description of several key terms and expressions used throughout the thesis. The terms described in this glossary are denoted italic in the main body of the text, when they first appear. For other occurrences we refer to the Subject Index.

Activity-Based Costing (ABC); the ability of the firm's cost accounting system to trace operating costs to specific products, customers, channels, or logistics activities.

Actor; an organization or a part of an organization within the logistics network (division, department) which has specific objectives and its own decision making power or authority .

Agile logistics; concept aimed at short reaction times and accommodating demand for a new product or service caused by changes in the environment (events) within a predetermined lead-time.

Agility; the ability to react to demand for a new product or service caused by changes in the environment within a predetermined lead-time (usually a short logistics lead-time).

Arm's Length; an arm's-length relationship is one between unrelated persons, each acting in their own self-interest. A related person includes the others, but is not limited to the other actors.

Asset Specificity; the relative lack of transferability of assets intended for use in a given transaction to other uses. Specific assets have little value beyond their use in the context of a specific transaction.

Back haul; the return movement of a means of transport (for example truck or barge) which has provided a transport service in one direction and is used for the backhaul.

Backlog; customer orders that are received and administrated but are not yet shipped (due to out-of-stock, lack of capacity); this also includes the backorders and future orders.

Bi-level optimization; In this type of optimization problem a lower and upper level problem is defined. Similarly, two problem's objective functions are distinguished that both need to be fulfilled.

Bounded Rationality; the capacity of the human mind for formulating and solving complex problems is limited compared with the size of the problems whose solution is required for objectively rational behavior.

Break-Bulk; the separation of a single consolidated bulk load into smaller individual shipments for delivery to the ultimate consignees, customers, or end-users.

Business logistics; the entire process of materials and products moving into, through, and out of a firm. Including planning, implementation, and control of product and information flows.

Carrier; a firm which transports goods or people via land, sea or air. For example a trucking company, or an aircraft carrier that provides its services under a specific contract.

CEMT; waterways are divided in six classes (CEMT classification), according to the maximum allowed tonnage and the geographic area of competence of waterway managers.

Center-of-Gravity Approach; planning methodology for locating warehouses at approximately the location representing the minimum transportation costs between the distribution centers and the markets.

Channel; a channel is a particular structure or path defined by a sequence of processes and the actors owning or operating them, and the relationships between them (Verduijn 2004).

Collaboration; an affective, voluntary, mutually shared process where two or more actors work together, have a mutual understanding, a common vision, share resources, and achieve common goals.

Collaborative Planning, Forecasting and Replenishment (CPFR); process whereby partners can jointly plan activities from production of raw materials to delivery of end products.

Commodity; an item that is traded in commerce. The term usually implies an undifferentiated product ('commodity type product') competing primarily on price and availability.

Continuous Replenishment (CR); partners can jointly plan key supply chain activities from production and delivery of raw materials to production and delivery of final product to the end customers.

Contract Carrier; a carrier that does not serve the general public, but provides transportation services for hire for one or a limited number of shippers under a specific contract.

Cost of Goods Sold (COGS); amount of direct materials, direct labor, and allocated overhead associated with products sold during a given period of time. According the Generally Accepted Accounting Principles (GAAP).

Cross-docking; system in which products received at the warehouse are not stored, but readied for shipment. This requires close synchronization of all inbound and outbound flows.

Customer Allocation; in order management and administration, allocation of available inventory to customer and production orders (linking the available stock/capacity to a customer).

Customer Order; an order from a customer for a particular product or a number of products. It is often referred to as an actual demand to distinguish it from a forecasted demand.

Customer service; supporting activities adding value to a product. This value added in the exchange process might be short-term, as in a single transaction, or longer-term, as in a contractual relationship.

Cycle inventory; an inventory management system where counts are performed continuously (cycle counts), often eliminating the need for an annual overall inventory cycle count.

Cycle time; the time between subsequent initiations of a repetitive process. For example the loading of a vehicle, the picking of an order or the cycle time between two dispatches.

Decoupling point; a point in the supply chain which provides a buffer between differing input and output rates, at this point the order can be made customer specific (pull).

Deterministic Models; models where no uncertainty is included, for example, inventory models without safety stock considerations or and demand fluctuations.

Direct delivery; the conveyance of goods directly from the vendor to the buyer. Frequently used if a third party acts as intermediary agent between vendor and buyer without temporary storage.

Down time; the period of time when a work station is not available for production due to a functional failure or maintenance that needs to be conducted on the machines or equipment.

Economic Order Quantity (EOQ); inventory model that determines how much to order by determining the amount that will meet customer service levels, minimizing ordering and holding costs.

Efficient Boundary; the boundary indicates the activities that a specific firm performs itself. All other activities are placed outside the firm based on the trade-off between production and governance costs.

Efficient Consumer Response (ECR); a demand driven replenishment system, common in food retail, designed to link all actors in the channel to create a flow-through distribution network (KSA 1993).

Flexibility; the ability to adapt to unexpected operational circumstances, enabling a firm to improve responsiveness and deliver a previously unidentified need by rapidly changing between output levels.

Focused Factories; strive for a narrow range of products, customers or processes and optimize performance to achieve economies of scale on few dimensions while sub-optimizing on others.

Fourth Party Logistics service provider (4PL); a 4PL entity established as a joint venture or long-term contract between a primary client and one or more partners focused on logistic services.

Full-Truck-Load (FTL); is the abbreviation of the Full-Truck-Load and is, for example, the equivalent of 26 pallets in a truck-trailer combination and consists of about 60 m3 in an average sized truck.

Gain Sharing; a method of incentive compensation (benefits, cost reductions) where supply chain partners share collectively in savings from productivity improvements.

Globalization; the process of making something worldwide in scope or application. Largely caused by the liberalization of world trade and the geographical specialization of production.

Inbound Logistics; the movement of materials from suppliers and vendors into production processes or storage facilities of the focus company.

Inventory Management; the process of ensuring the availability of products through inventory administration and governance of the entire inventory in the pipeline (inbound and outbound).

Joint Venture; a strategic alliance between two or more parties to undertake economic activity. They agree to create a new entity by both contributing equity, and they then share in the profits and losses.

Just-In-Time (JIT); an inventory management philosophy aimed at reducing inventory by delivering products, components, or materials just they are needed (Hutchins 1988; Taylor 2001).

Lead-time; the time between the initiation of a process and its completion. In this dissertation used to denote order lead-time; the time between the placement of the order and its delivery.

Lean Logistics; the objective is the complete elimination of waste and inefficiency throughout the purchasing, supply, distribution, and business operations chain.

Less-then-Truck-Load (LTL); the abbreviation of a Less-then-Truck-Load and is less than 26 pallets in a truck-trailer combination. Network consolidating LTL-shipments are referred to as LTL-networks.

Logistics network; the network of actors that are involved, through upstream and downstream linkages, in the processes and activities that each produce value (products and services).

Lot-size; the number of units in the lot or production batch and directly affecting inventory and scheduling. Small lots reduce variability in the system and smooth production

MPEC problem; is the abbreviation of Mathematical Program with Equilibrium Constraints (MPEC), a common equilibrium problem in transport modeling.

NP-Complete; problems which are NP (verifiable in non-deterministic polynomial time), in complexity theory, are the most difficult problems to solve in NP.

NP-Hard; a problem is NP-hard if an algorithm for solving it can be translated into one for solving any other NP-problem problem and means "at least as hard as any NP-problem".

Opportunism; the suggestion (associated with transaction cost analysis) that a decision-maker may unconditionally seek his/her self-interests, and that such behavior cannot necessarily be predicted.

Order processing; the data capture, order receiving, order administrating, and processing and checking the information which arises with an order, usually limited to customer orders.

Outbound Logistics; the process related to the movement and storage of products from the end of the production line to the end user. Also referred to as physical distribution.

Pallet; the platform which cartons are stacked on and then used for shipment or movement as a group. Pallets may be made of wood or composite materials. Referred to as loading unit.

Procurement; the business functions of procurement planning, purchasing, inventory control, traffic, receiving, incoming inspection, and salvage operations. Also referred to as purchasing.

Product Characteristics; all of the elements that define a product's character, such as size, shape, weight, density, packing density, etc. Also referred to as the logistics characteristics.

Product Life Cycle (PLC); the time between acquisition and disposal of the product. In the marketing sense this includes: introduction, growth, maturity, saturation, decline and end phase.

Pull system; in a pull system, a customer order sends replenishment order back through the supply chain from retailer to distributor to manufacturer, goods are pulled through the supply chain.

Push system; The process of building product and pushing it into the distribution channel without receiving any information regarding requirements. Also see: Pull system.

Quick Response (QR); a retail strategy which combines a number of tactics to improve inventory management and logistics efficiency, while speeding inventory flows (Fernie 1994).

Radio Frequency Identification (RFID); a method of storing and remotely retrieving data using devices called RFID tags, small objects that can be attached to or incorporated into a product.

Reliability; a carrier selection criterion that considers the variation in carrier transit time; the consistency of the transit time provided, the product availability, perfect order ratio, etc.

Replenishment; the process of moving or re-supplying inventory from a reserve storage location to a primary picking location, or to another mode of storage in which picking is performed.

Responsiveness; the ability to react (make the delivery) to demand for products that are difficult to forecast within a predetermined (usually short) customer lead-time.

Safety Stock; the extra inventory a company holds above normal needs as a safety buffer against delays in receipt of supply and raw materials or unforeseen changes in the customer demand.

Set-up time; the time required for preparing machines and other production resources for carrying out operations. Shifting from one output level to the next.

Shipping frequency; the number of times per standard period of time (day, week, month) that shipments are (or will be) dispatched. For example, a daily or weekly service.

Stochastic Models; models where uncertainty is explicitly considered in the analysis. A well-known type of model to deal with choice behavior that is used in logistics is the Logit model

Stock Out; a term used to refer to a situation where no stock was available to fill a request (customer order) from a customer or production order during a pick operation.

Stock-Keeping-Unit (SKU); a category of unit, products, or components with a unique combination of form, fit, and function. Unique components held in stock and administrated separately.

Supply Chain Management; the co-ordination and management of the flows of goods and information from suppliers and to the consumer in the total logistics network.

Third party logistics (3PL); supply of logistics related operations between traders by an independent organization (referred to as a third party logistics service provider).

Time compression; creates opportunities to reduce inventory levels, shorten customer lead-times and logistics costs. By reducing the lead-times and removing waste in the supply chain.

Time to Market; the time between acquisition, design and production of the product and the introduction of this same product at the marketplace, ready for the customer to buy.

Time-Based Competition; creating the ability, through reduction in delivery times, to achieve an advantage that enables faster growth, increased market share, and control overhead and inventory.

Transaction Costs; costs incurred when making an economic exchange. For example, costs for negotiating, contracts, and enforcing (search costs, bargaining costs, policing and enforcement).

Tri-level optimization; in this type of optimization problem, in addition to a lower level and upper level problem a third problem is defined. Similarly, three objective functions are distinguished.

COLLABORATIVE LOGISTICS AND TRANSPORTATION NETWORKS

A MODELING APPROACH TO HUB NETWORK DESIGN

1 Introduction

During the last thirty years, the imperatives of the customer service and cost efficiency have pushed firms to change their strategy and logistics organization, resulting in the centralization of production and distribution, and the reduction of inventory. Although for many companies these changes in strategy have been a part of a broader response to growing global opportunities and increased levels of international competition, they have led to increased competition and marketing pressure, dictating shorter lifecycles and lead-times, a larger variety of products and production in smaller quantities. Next to this centralization and inventory reduction, the need for time compression has reduced the shipment size, increased the frequency of material movement, and introduced a series of new management principles and approaches, such as *JIT*, *Quick Response* (QR), *Lean Logistics*, *Agile Logistics*, and *Efficient Consumer Response* (ECR) to help firms accelerate their logistical operations. However, this mounting pressure to time-compress logistical systems may seem at odds with the lengthening of the supply-chain links caused by centralization. Consequently, one of the major difficulties that a company faces in the implementation of both strategies – globalization and time based competition – is that they make contradictory demands on its resources. Long transit times from distant production facilities can, after all, make the international supply chain unresponsive to short term variations in demand. And this is not the only dilemma faced in today's logistics. Of course, there is the ever-present trade-off between logistics service quality against logistics costs. More specifically, on the one hand the firm is faced with a fragmentation of flows due to smaller, customized shipments at higher frequencies; on the other hand the need to maintain control over cost levels through benefits of scale in the logistics network is as high as ever.

The evolution of logistics networks during the last decades can be characterized by a strong rationalization of business processes. Companies have become more aware of the impact that their logistics organization can have on the costs of doing business and on the degree of satisfaction of their customers. This ongoing rationalization has led to a constant search for economies of scale in the supply chain, which has been an important parallel development in line with the changes manufacturing and further globalization. As a result the logistics costs as a percentage of sales dropped 40% from 1981 to 2001 (Piper Jaffray 2002).

Logistics is a vitally important component of the economy, with worldwide logistics expenditures of about € 3,500 billion in 1998 (Figure 1-1). These costs were equal to 10.1% of GDP in 1998. Figure 1-2 illustrates the relative importance of logistics as a percentage of sales. In this figure the different components are broken down into marketing, production, logistics and profit margin, together making up for the total sales. In Europe the average logistics costs were 10.4% of sales in 1998. This percentage has declined extraordinarily over the past 20 years; from 16.2% of GDP in 1981 to 9.5% of GDP in 2001 (A.T.Kearney 1999, McKinnon and Forster 2000). The logistics costs can be broken down further in different activities depicted in Figure 1-3. Since 1981 the transportation costs have declined by 24% as a percentage of GDP.

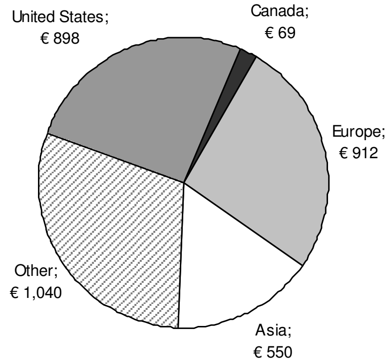

Figure 1-1: Global logistics market, 1998 worldwide logistic expenditures in trillion. Source: Piper Jaffray *et al.* (2002).

This entire decline occurred during the 1980s, however, as since 1991 transportation has been steady at about 6% of GDP. Inventory carrying costs declined by more than 60% between 1981 and 2001, as faster and more reliable transportation allowed companies to invest in less inventory and consolidate it into fewer locations. It is expected that, as the service demands of the customers increase even further, the demands on the performance of the logistics network will increase even further (UPS 2005).

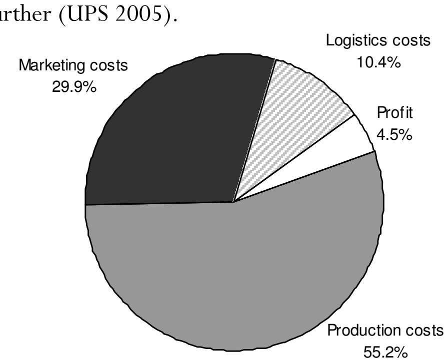

Figure 1-2: Average costs as percentage of sales in Europe 1998. Source: A.T.Kearney (1999;2004).

A strategy that has become more and more apparent is seeking collaboration with partners in order to achieve the necessary scale and scope to meet these demands. The difficulty when searching for such a partnership in logistics is finding the most appropriate scope, type and form of collaboration. Even more so because the impact of a partnership or collaboration on the logistics organization, governance structure, number of facilities, inventory policy, etc. can be far-reaching. The decision to seek an in-house solution, outsource or participate in a collaborative network is one of the key decisions in business and in this dissertation. The decision to participate in a collaborative network does always have to be seen in the light of other options open to the firm (e.g. Outsourcing, In-house solution or extension of the current solution) and becomes more and more relevant with the introduction of partnerships, *Collaborative Planning, Forecasting and Replenishment* (CPFR), *Just-In-Time* (JIT) and the collaboration concept in logistics. Before the objective and research approach is presented, we will elaborate on the definition of Supply Chain Management and the term Logistics Network, as we will use these terms often in this dissertation (section 1.2). Following the need to gain insight into the extensive implications participating in a collaborative network has on the logistics network, we will discuss the available models and the need for innovation in modeling logistics decision-making (section 1.3). The modeling approach we propose will be briefly discussed before we present the overall objective and key research questions in section 1.4. Finally, in section 1.5 the outline of this dissertation and overall structure of the research approach is illustrated. But firstly, in the following section, the pronounced trend towards collaboration in logistics networks is discussed.

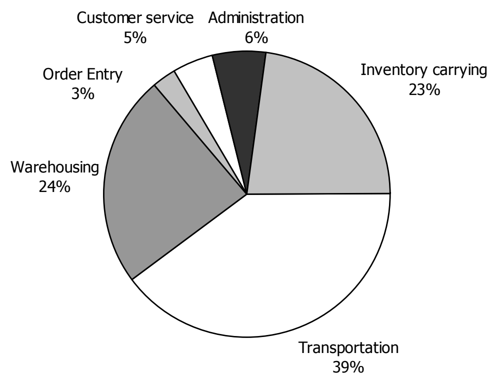

Figure 1-3 : Average costs as percentage of total logistics costs in 1998.
Source: A.T.Kearney (1998;1999;2004).

1.1 Collaboration in logistics

The logistics costs as a percentage of sales have dropped considerable; it follows that there are major implications for Logistics Management, as can be witnessed by the centralized production and inventory, increased transport distances, and fragmentation of flows. In search of opportunities and competitive advantage, companies focus more and more on collaboration because an important contribution in achieving these goals can be made by other organizations in the logistics network. The objective, scope and type of the external relationship is the result of the business strategy decisions related to the products and markets that the organization wants to serve and its core competences. The firm has to decide on what activities and processes the organization wants to get involved in and whether or not to collaborate with other actors in the logistics network.

As more and more production processes become increasingly specialized, an increasing part of the added value is placed outside the company's own facilities, making co-ordination and communication with partners in the supply chain vitally important. This is exactly what happened towards the end of the 20th century, when the focus changed from internal efficiency in the logistics function to external relations between parties in the total supply chain (Skjoett-Larsen 2000). There are circumstances, however, where working in a collaboration could be more appropriate. If, for example, the activities or products are of great importance for the buyer and the supply market is highly complex, making procurement difficult, outsourcing might be too uncertain (Kraljic 1983), or when both supplier and buyer need to invest, a market solution may not to be preferred. It can be argued that the largest potential for improvements is not found inside an individual company, but in the interfaces between independent companies in the supply chain. Nowadays, as the potential of internal reorganization appears to have been virtually completely exploited, we see new forms of collaboration and integration of supply chains emerging, where firms co-operate to share the costs of using logistics facilities and services.

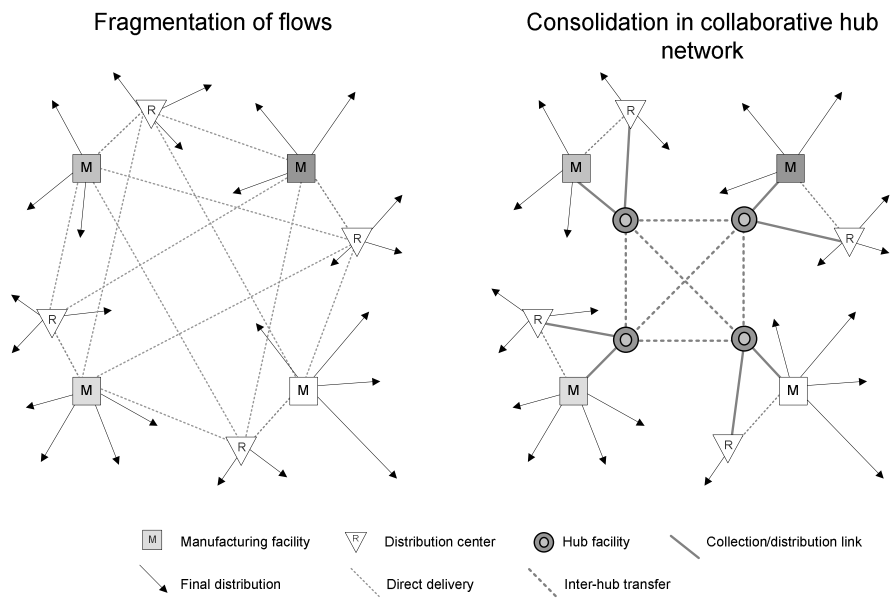

Figure 1-4: Fragmentation and consolidation of flows through the concept of a collaborative hub network.

The term *Collaboration* has taken on several interpretations when used in the context of supply chain management and has been described in the literature as a business tool that builds sales (Andraski 1999); as an interaction among peers sharing a common set of goals and measures (Citera *et al.* 1995); as a process for parties to jointly search for solutions (Heackel 1998); as a relationship in which trading parties develop a long-term cooperative effort (Sriam *et al.* 1992); and as a process of decision-making among inter-dependent parties. It involves joint ownership of decisions and collective responsibility for outcomes (Gray 1989). Common to many of these descriptions is a long-term relationship between partners that work together. Based on Schrage (1990), we define collaboration as: "*an affective, voluntary, mutually shared process where two or more actors work together, have a mutual understanding, a common vision, share resources, and achieve common goals. Key dimensions are the cross organizational scope, the commitment to working together, and a common bond or goal*."

By collaboration companies can achieve: (1) *Asset or Cost efficiency;* a potential for cost reduction provides a strong reason to partner, (2) *Customer service* integrating activities in the supply chain through partnerships can often lead to service improvements for customers in the form of reduced inventory, shorter lead-times, and more timely and accurate information, (3) *Marketing advantage;* a third reason for entering into a partnership is to gain a marketing advantage, and (4) *Profit Stability or Growth;* a potential for profit improvement is a strong driver for most partnerships.

Relationships between organizations can range from arm's length relationships to complete vertical integration of the organizations. Literature on relationships in logistics networks shows a variety of terms and perspectives: supply chain partnerships, supply chain collaboration, supplier-buyer relationships, purchasing, and supply management. It is evident that the type of collaboration can have great influence on the logistics network and the decision-making processes, and the choice between in-house organization and collaboration is a fundamental decision in logistics.

For areas as vital as logistics, firms are often reluctant to transfer managerial responsibility to or share it with a third party. Fears about the loss of control, problems in maintaining customers' goodwill and the inability to replace or supplement at short notice a system that fails to perform are reasons given by logistical managers for not seeking collaboration and contracting out. Therefore an answer to the question: "*under what circumstances will organizations decide to collaborate with third parties?*" is crucial in order to be able to design a logistics network in which the different actors collaborate. A methodology that can be used in this context is *Transaction Costs Analysis*, a methodology that is concerned with the minimization of the sum of production and governance costs. But next to production and governance costs, the dominance of a partner, uncertainty, the frequency of the decision-making, and issues of trust play an important role. However, if these factors influence the choice behavior, it is apparent that when searching for logistics network solutions due to market pressure that reduce costs or increase the service, these factors need to be taken into account. Especially when working towards the implementation of these networks, feasible network solutions need to found.

In the many initiatives that have been reported in literature concerning collaboration, the search for cost reduction and asset efficiency is dominant. A preferred strategy, for example, to counter the discussed fragmentation of flows is to operate in a hub network in which the flows are consolidated and economies of scale can be achieved. The type of network is designed for many distribution problems in order to reduce logistics costs (Daganzo 1999). In these networks serving many origins and many destinations, one important function of the hubs or transportation terminals is to consolidate small shipments into vehicle loads. As O'Kelly and Bryan (1998) so aptly put it: "*economies of scale, due to the amalgamation of flows, provide a raison d'etre for hub systems*".

Consolidation in these types of networks allows for more efficient and more frequent shipping by concentrating large flows onto relatively few links between hubs. Although use of indirect (that is via a hub) shipment may increase the distances traveled, the economies of scale due to the larger volume can reduce the total cost. These configurations can reduce and simplify network construction costs, centralize commodity handling and sorting and allow carriers to take advantage of economies of scale. Figure 1-4 illustrates the fragmentation of flows and the impact a collaborative network can have on the economies of scale. For a number of manufacturers and retailers the direct road delivery links are depicted. When consolidating these flows in a collaborative network, economies of scale can be achieved in the inter-hub transfer that need to counter the increasing transport distances and costs incurred for handling. These *Hub-and-Spoke* networks are applicable to many different types of problems.

1.2 The logistics network

Before we proceed we will explain the notion of logistics and hub networks, and several key terms and definitions will be presented that we will use throughout this thesis. Whenever there is a rapid change in a field, new terms and definitions appear. Logistics is no exception. Business logistics, physical distribution, materials management, distribution engineering, logistics management, and supply chain management are only some of the terms being used to describe approximately the same subject, logistics. Logistics can be defined in a number of ways depending on one's view of the world; here it is taken to be a set of activities whose objective is to move items from an origin to a destination in a timely fashion (Daganzo 1999).

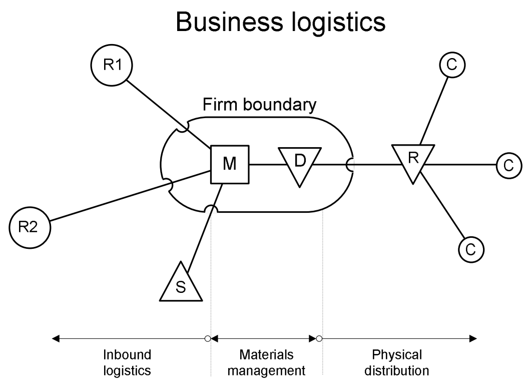

Figure 1-5: Overview of the logistics network with the inbound logistics, materials management, and physical distribution.

In this thesis we use six important key terms: *business logistics*, *inbound logistics*, *materials management*, *physical distribution*, *logistics network*, and *supply chain management*. Business logistics describes the entire process of materials and products moving into, through, and out of a firm. Inbound Logistics covers the movement of materials received from suppliers; procurement and inbound transportation. Materials management describes the movement of materials and components and processing within a firm. Their central objectives are to ensure that the production function has the necessary input at the right time and place in a timely and efficient manner. Physical distribution refers to the movement of goods outward form the end of the assembly line to the customer (Johnson and Wood 1996). Supply chain management has been of significant importance since the early 1990s, although the approach, or rather the concept, was introduced in the 1980's (Oliver and Webber 1992). In Figure 1-5 we illustrate these first five terms. In this figure we distinguish different actors, and their relations with one another. Supply chain management is an influential ingredient in today's literature and thinking in the field of logistics. It may also be an influential ingredient in the field of marketing theory, since there is a close interrelationship between marketing activities and logistics activities in marketing channels (Mentzer *et al*. 2001a; Chandra and Kumar 2000; Levy and Grewal 2000; Lings 2000). Supply chain management has achieved the status of a generic term for a business philosophy to implement various systematic processes that create competitive advantages and profitability by the help of the others in the marketing channels. There are many proposed definitions of supply chain management in literature. Lummus *et al.* (2001) conclude: "*supply chain management includes the logistics flows, the customers order management, the production processes, and the information flows necessary to monitor all the activities at the supply chain nodes*". Mentzer *et al*. (2001b) conclude that: "*supply chain management is the management of close inter-firm relationships, and that understanding partnering is important in developing successful supply chain relationships*".

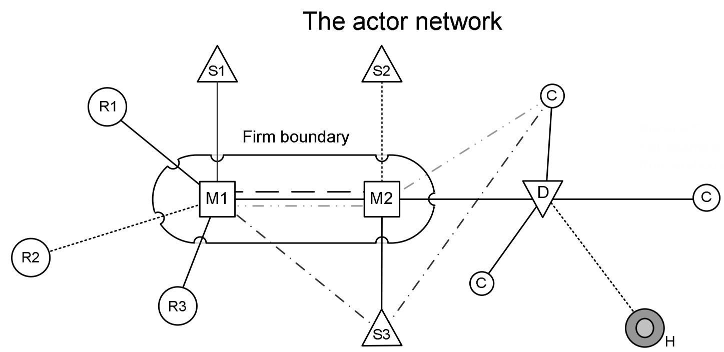

Figure 1-6: The actor network with information, product, payment and order exchanges (denoted by the different line-types)..

Another definition of supply chain management, according to Ellram and Cooper (1993)), is that it is an approach whereby: "*the entire network, from the supplier through to the ultimate customer, is analyzed and managed in order to achieve the best outcome for the whole system"*. Whilst the phrase 'supply chain management' is now widely used, Christopher (1998) argues that it really should be termed demand chain management to reflect the fact that the chain should be driven by the market. And the chain should be replaced by the word network since there will normally be multiple suppliers and, indeed, suppliers to suppliers as well as multiple customers and customers' customers to be included in the total system. Based on Christopher (1992) we define that: "*The logistics network is the network of actors that are involved, through upstream and downstream linkages, in the different processes and activities that each produce value in the form of products and services in the hands of the consumer*". Based on Carter *et al.* (1995), we define supply chain management as: "*The co-ordination and management of the flows of goods and information from suppliers and to the consumer in the total logistics network*". These linkages between the actors[1] within the network[2] are products, information, orders, or payments.

[1] An actor is an organization or a part of an organization (division, department) which has specific objectives and its own decision making power or authority.

[2] It can either refer to a particular industry, e.g. the automotive industry or the electronics industry or can be interpreted as the collection of all firms that are or may be relevant in the provision of goods and services.

From here onwards we will frequently make use of a network representation in which the actors in the logistics network are depicted and the interactions (products, information, orders, payments, contracts) are illustrated. To specify this network representation we will first describe an example. We distinguish three different layers in our network representation: (1) *the actor network*, (2) *the service network*, and (3) *the physical network*. In Figure 1-6 an example of the actor network is illustrated. In this example several actors, manufacturers, retailers, suppliers, distributors, and customers are denoted by different symbols. In addition, the interaction in products, contractual exchanges, orders, information and payments are included. The symbols used to denote the different actors, are consistent throughout this dissertation.[3] The interaction between the different network actors or objects and the line-types used will be declared separately as the variety of these interactions and linkages is considerable.

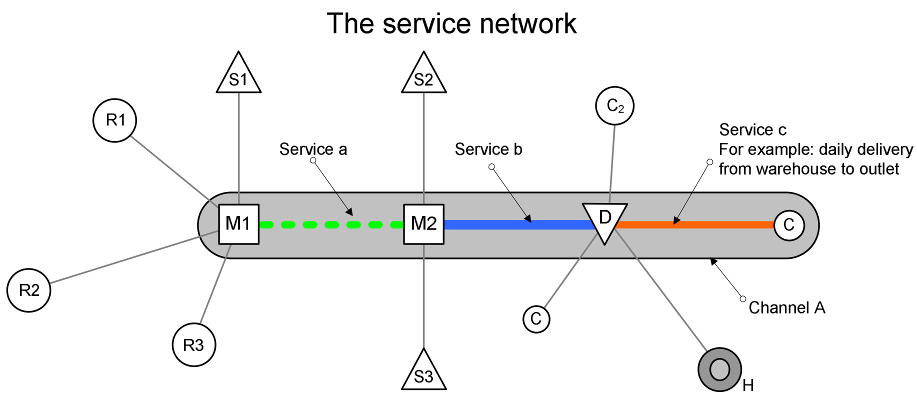

Figure 1-7: The service network with several particular structures or paths (channel structure).

In our example, presented in Figure 1-6, two distinct production stages in the logistics network, represented by M1 and M2 are included (denoted by a square). The raw materials are represented by R1, R2 and R3 (denoted by a circle). Component suppliers are represented by S1, S2 and S3 (denoted by a triangle), and the distributor D1 is denoted by a triangle. Finally, a solid line between two actors represents an actual transaction and a dashed line a potential transaction. The boundary of the focal firm is denoted by a closed curve that includes those activities that the firm does for itself. The closed curve that defines the efficient boundary of the firm in Figure 1-6 includes, in addition to the primary manufacturing activities M1, a secondary manufacturing stage M2. Obviously this is arbitrary and merely illustrative. It also oversimplifies greatly. It is relatively easy, however, to elaborate the scheme to add to the core, to consider additional components, to include several material stages and consider backward integration into these, to break down distribution, and indicate the scope of the collaboration.

[3] See the *Glossary of symbols* on page IX for an overview of all symbols used.

The second level in our network model is the service network. It '*accommodates*' the different channels[4] in the actor network, or to put it another way: different channels make use of the same service network. Where for example marketing and the related channels in fact express the suppliers' (shippers') demand side, the services express the supply side. Service networks are aimed at enhancing efficiency, because they bundle resources (such as distribution centers with their personnel, equipment, and storage facilities): facilities can therefore be jointly used.

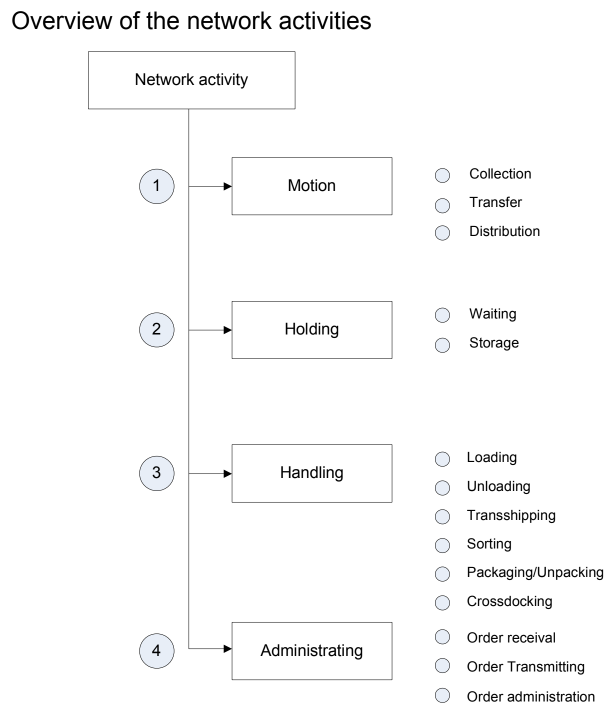

Figure 1-8: The different network activities.

A physical distribution service network is the integrated set of distribution services offered by one or a group of co-operating actors. Different routes or paths represent the alternative physical distribution options within that network. In Figure 1-7 a service network is illustrated with channel (A) that consists of three services a, b, and c, starting at manufacturer M1, ending at the customer. In these representations a subscript indicates the number of actors, for example, in Figure 1-7, C_2 indicates two customers. The interaction in flows between the actors is multi-product. If the interaction is single product this will be mentioned. Finally, we distinguish the physical network layer (not illustrated). The physical network is characterized by its network attributes and is a part of the service network. Attributes often used to describe the physical network are mode, costs, distances, and reliability performance. In tracing the

[4] A channel is a particular structure or path defined by a sequence of processes and the actors owning or operating them, and the relationships between them. It is a structure in the sense that it conveys a design for the fulfilment of a flow of orders, but not the flow itself. Once established, the design is available, but may be dormant until the channel is used for fulfilling one or a sequence of orders that flow through the channel (Verduijn 2004).

path of an item from production to consumption, it is handled from the production area to a storage area, held in this area with other items, where they wait for a transportation vehicle. It is then loaded into this vehicle, transported to the destination, and unloaded, where it is then handled for consumption at the destination. These operations incur costs, related to *motion* overcoming distance, costs related to *holding*, overcoming time, and costs related to *handling*. The last category is related to the *administration* of the orders.

Motion costs are classified as collection, transfer, or distribution costs, referring to the function of the transport activity. Holding costs include storage and waiting costs and, as the former category implies, these costs are incurred for the rent of the storage space (rent, maintenance, security), and the latter category are costs covering the costs of delay to the items, including the opportunity cost of the capital when it is tied up in storage. Handling costs are classified as loading and unloading a vehicle, transshipment (between two different modes of transport), sorting, order-picking, packaging, and cross-docking. Then, finally, administrating consists of activities related to the receipt, transmittal and administration of the order. Together these network activities make up for all cost-incurring activities that we will consider when calculating the costs of a network solution, derived from the network design methodology. Next to these activities there are of course additional activities to be distinguished in the logistics network; governance, taxes, capital costs, etc., but here we limit ourselves to the activities and related costs presented in the figure above, as these determine the logistics network structure.

1.3 The need for modeling logistics

As virtually every aspect of manufacturing and logistics has changed over the last decades and will keep on changing, research to develop efficient and effective methodologies to assist operations and logistics managers in the formulation of competitive operations and logistics strategies is now as important as ever. It is evident that a decision concerning the structure of the logistics network, for example the number of warehouses in the network, influences the inventory policy and transport planning. To understand these inter-dependencies between the different levels of decision-making in logistics the use of models is essential.

The myriad of relations and interactions between the actors operating in the logistics network poses structurally complex network design problems for each of the organizations individually and to the network as a whole. Whereas contractual relationships are one-to-one by definition, the network design problem is a many-to-many problem. Apart from questions concerning the locations and number of production sites and warehouses, tactical and operational issues of stock positions, mode choice and delivery frequency have to be addressed. However, in many organizations the different logistics sub-functions are controlled and optimized independently; in theory, modeling and practice.

Nowadays, as the potential of internal reorganization appears to have been virtually fully exploited, we see new forms of collaboration and integration of supply chains emerging, where firms co-operate vertically and horizontally, adding more complexity to the design problem, often making the design problem a multi-objective problem. Not only is it crucial for a company to gain insight into the impact that a change in structure has on the inventory levels, transportation, vehicle routing and other operational aspects; the decisions made by the other actors in the network are just as important. This is especially the case when participating in a collaboration. Consequently, decisions related to participating in a partnership are among the most critical in logistics. Both the costs of the logistics network and the quality of customer service that can be provided by the system are significantly affected. To support this highly complex decision-making process, various modeling techniques have been developed for the different actors and the literature on this subject is vast as we will discuss later on in this thesis (Chapter 4). We focus primarily on two different classes of models in this thesis: (1), *the network optimization models*, and (2) *the network simulation models*. The former is used to design and optimize logistics networks, while the latter to evaluate different network designs and for *what-if* analyses. In the review of existing network optimization models we make a further distinction between facility location, inventory management and transportation models; models used for strategic network design.

Considerable progress is constantly being made in supporting the decision-making process in logistics network design, as witnessed by the increasing number of success stories reported in logistics literature (Current *et al.* 2002; Crainic 2002; De Kok and Graves 2004). This progress can be largely attributed to the advances made in optimization techniques, in information technology and information systems. As algorithmic tools evolve, so do the complexity and realism of the problems that can be tackled. Finding an optimal solution, in the ever faster-changing logistics environment is one thing, the path to get from *Ist* to *Soll* is as important as ever. This aspect, however, has received very little attention.

Thus far, the design of a logistics network in which the different actors collaborate in order to decrease costs or increase the service level is an issue that has received little attention in the literature. This is in contrast to the amount of attention the organizational issues of partnerships, alliances and supply chain management have received in recent years. Camarinha-Matos and Afsarmanesh (2004) state: *"After an initial phase in which in spite of the considerable investments on collaborative networks, most of the approaches were highly fragmented and case-based, it is now urgent to consolidate and synthesize the existing knowledge, setting a sound basis for the future. One of the main weaknesses in the area is the lack of appropriate theories, consistent paradigms and formal modeling tools"*.

Instead of solely minimizing the total costs in the logistics network or minimizing the costs of individual companies, when designing a collaborative network it is necessary to take into account the scope of the collaboration and the type of partnership. We emphasize that the design of logistics networks and especially collaborative logistics networks is interdisciplinary by nature since it involves manufacturing, transportation and logistics, as well as marketing and transaction costs economics. It has been the subject of a growing body of literature (Stadlter and Kilger 2000; Ploos van Amstel and Van Goor 2001) with the associated research being both conceptual in nature (Poirier 1999; 2002), due to the complexity of the problem and the numerous actors in the network, such as retailers, manufacturers, service providers, carriers involved in the transactions, as well as analytical (Bramel and Simchi-Levi 1997; Syam 2002). Daganzo (1999; 2002) for example, examined logistics systems in an integrated way and showed how to find rational structures for such systems. Many researchers, in addition to practitioners, have described the various networks that underlie logistics network analysis. However, the framework considered has been primarily that of single objective optimization. In this dissertation, in contrast, we focus on both the behavior of various decision-makers and the different objectives they might have. This is also referred to as a bi-level optimization problem, or, it can be argued that this can even develop into a tri-level optimization problem when the consortium operates as an independent actor. In Figure 1-9 a different scope is illustrated for several optimization problems. When a warehouse layout, capacity or stock position is optimized it can be considered an internal optimization. When the *Economic order quantity* (EOQ) is optimized on a single link, for example between manufacturers M1 and M2, this can be considered a dyad or link optimization. If, for example, the pipeline inventory of M1, M2, and D is to be optimized, this could be formalized in a collaboration, making this the scope of the collaboration.

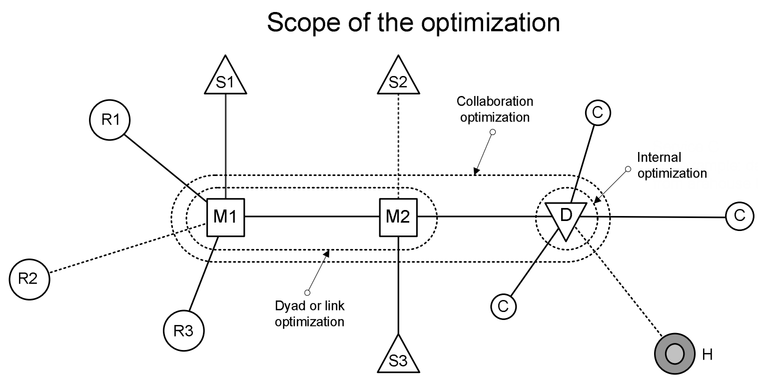

Figure 1-9: the scope of the collaboration and the implications on the objective function.

Given the type of partnership and objective (cost minimization, inventory reduction, service increase), a specific solution would be the outcome. As we will focus on the design of collaborative networks, and especially on the design of collaborative hub-networks, we will make use of the literature on this topic (O'Kelly 1986a; Current *et al*. 2002). House and Karrenbauer (1982) argue that logistics models should account for the following characteristics: (1) the dynamic and evolutionary nature of logistics systems, (2) the stochastic nature of input to such models and uncertainties, (3) non-linear costs, (4) multiple objectives of the firms, (5) multiple products, (6) multiple inventory echelons, and (7) capacity restraints on components of the system. They conclude: "*there is yet no universal model capable of dealing with all variables, all situations and all possible scenarios*". "Since then, such a universal model has not yet been developed and it never will be, even striving to do so would be foolhardy: *nevertheless integrated logistics models representing as many of the functional logistics areas and model characteristics as possible will provide a greater understanding of the trade-off's involved in logistics*" (Daskin 1985). This was certainly a key objective of this research: trying to capture the key trade-offs in logistics that influence the logistics network design, the decision-making process in collaboration, and the development path of logistics networks.

In this dissertation we present a new modeling framework in which we combine network design models, transaction cost analysis, and simulation techniques into a comprehensive approach. The innovation is sought in the combination of these three, enabling us to design a hub-network, more specifically a collaborative hub-network, based on transaction cost analysis, gain insight into the feasibility of the development path, and evaluate the network solutions. The success of such an integrated model, indeed, the success of any logistics model, should not be based solely on the range of logistics functions represented, the number of complicating characteristics incorporated or the elegance of the formulation and solution procedure employed. These are important criteria, but they alone do not suffice in assessing integrated logistics models. Rather, such models should also be judged based on their ability to address the real concerns of the model users: decision makers, managers and planners. This was the aim during the research, can we support the decision-making process and provide the actors with an actual design, evaluate these network solutions, and support the implementation process of a collaborative hub network.

1.4 Main objective and research questions

Having sketched the field of logistics, the constant search for economies of scale and scope, and the emerging field of collaborative logistics, we will now present our objective and primary research questions. Based on the state-of-the-art of network design models, simulation and organizational theory we conclude that there is a need for a comprehensive methodology capable of designing collaborative logistics networks; incorporating the different types of collaboration, the impact of transaction costs, specific investments, and additional collaboration contingencies (dominance, transparency, uncertainty). In terms of decision variables we focus on the decision to participate, locating hubs, connecting hubs, adding capacity on the hubs and inter-hub transfer, mode of transport, and the development path of the hub network. The type of network we focus on in this thesis is a hub network.

The main objective of this study is to develop and demonstrate a design and evaluation methodology for logistics and transportation networks in which the participants collaborate based on (1) the integral logistics costs, (2) the service requirements set by the users of the network, (3) the type of collaboration, and (4) the possible economies of scale throughout the logistics network. The following research questions need to be addressed in order to identify the modeling needs in logistics network design:

- (Q1) What are the main components of logistics costs that determine the logistics and transport network design?
- (Q2) To what extent are the existing network design and evaluation models sufficient and how can collaboration be incorporated in the network design methodology?
- (Q3) What is the impact of the different types of collaboration (for example objective, scope, term, horizontal, vertical collaboration) on the decision to participate and eventually on the network design?
- (Q4) What are the dominant service requirements set by the various users in logistics and how can these be included in the network design?
- (Q5) How can economies of scale and scope, present in the network, be taken into account in the network design?
- (Q6) Is it possible to set boundaries to the development path of the network, and search for a feasible path instead of searching solely for a feasible solution?

In order to answer these questions new analytical models will be developed in this thesis for designing collaborative hub networks. A comprehensive framework will be developed that will be based on economic objectives such as minimizing total costs, minimizing user costs and the preferred levels of service set by these users. This thesis analyses collaboration in logistics networks and the impact the different types of collaboration have on the network design and performance in terms of costs, lead-time and reliability. We develop an integral approach in which we introduce integral cost functions, we combine network design models, evaluation models, and organizational theory, and incorporate the capability to direct the network development. This uniform framework will be developed to classify not only the different levels of decision-making in logistics, but also the different types of collaboration, making it suitable for numerous design applications in which collaborations are involved. The key elements of a specific collaboration (for example the scope, objective, frequency, uncertainty, transaction costs, etc.) will be incorporated in the network design procedure making it possible to elicit the impact collaboration has on the network structure and performance. In addition, it will not only be possible to classify the characteristics of a collaboration and calculate the impact on the network structure, but the methodology can be applied to all levels of decision-making in logistics when dealing with collaboration.

In this thesis new perspectives will be presented on dominance in the logistics network and the influence of transparency, seen from a network design perspective, allowing the actors in the logistics network to assess the impact of dominant partners, trusting potential partners, and the influence of impact measurability, seen form the perspective of the specific actor, whether a retailer, manufacturer, service provider or carrier. The collaboration typology helps the actors to position themselves in the actor network and assess the impact the different types of collaboration have on the costs and logistics performance.

In the area of network design methodology we develop an integral network design approach in which we combine normative and descriptive approaches (e.g. optimization and simulation), and combine user optimization and system optimization (e.g. a bi-level optimization problem). The hub network design problem we focus on is a multiple assignment (customers can use more than 1 hub), combined with direct transportation and we introduce capacity restriction on the hubs and on the inter-hub transfers. In addition, we incorporate transaction costs that influence the decision of the actors to participate in the hub network, based on the performance of the network solutions (e.g. costs, lead-time, and reliability). This design methodology, yielding feasible network solutions and development paths, is new and is a considerable extension on the current hub network design approaches. We do not extend the current state-of-the-art of part of the simulation methodology, we make use of the available methodologies to evaluate the network solutions derived by the network design procedure. Based on case study research the methodology will be validated and tested using actual order and cost information. The findings, based on results of the application of the methodology for different types of collaboration, will provide guidelines for the design of collaborative networks, insight into the influence the development path of a network has on its feasibility, and will make it possible to evaluate these networks using simulation. The methodology will enable the decision-maker to assess different network solutions, a crucial step towards actual implementation of these networks.

1.5 Outline of the thesis

The scope of our research will incorporate *literature exploration* on the decision-making processes in logistics, modeling decision-making and collaboration in logistics networks, *theory development* resulting in a conceptual model, *model development*, and *case study analysis*. The research outline is presented in Figure 1-10. The encircled numbers correspond with the nine chapters of this thesis. For each chapter the type of research is indicated and, in addition, using the abbreviations Q1-Q6, the focus of the chapters on the specific research questions is indicated.

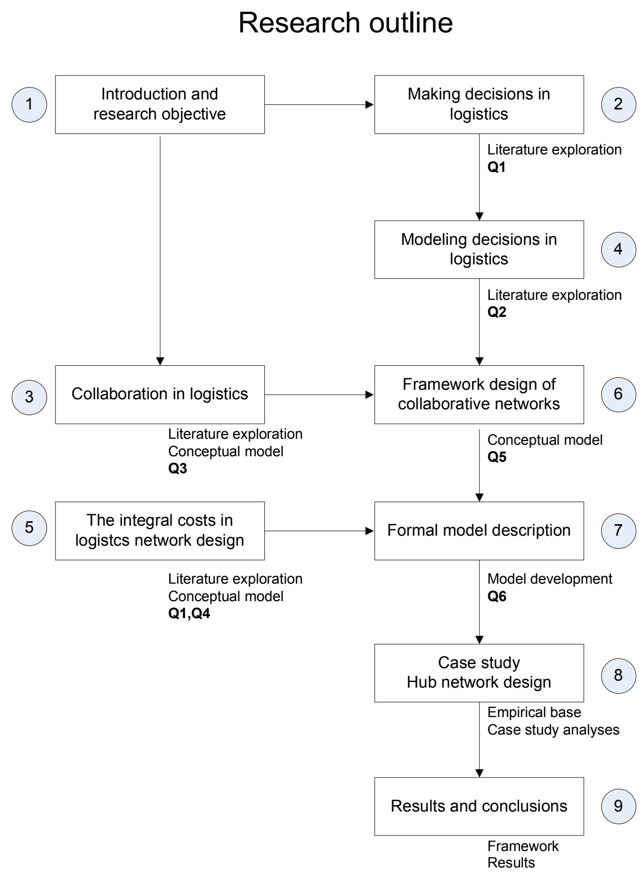

Figure 1-10: Outline of the research.

For example, Chapter 2, named *Making decisions in logistics*, reports on the literature exploration and focuses on research question Q1. Chapters 2, 3, and 4 form the basis of the theory, developing the conceptual model and network design framework mainly through an exploration of the literature. First the decision making processes and important issues in logistics are discussed in Chapter 2; dominant trends, influencing the design of logistics networks, like centralization, inventory reduction, time compression and globalization will be discussed. To deal with this changing environment, decision-makers in logistics make use of different modeling techniques. In Chapter 3 we will focus on modeling decision-making processes and the state of the art in modeling in logistics. We distinguish two different classes of models in this chapter: (1), the network optimization models, and (2) the network simulation models. The former, used to design and optimize logistics networks and the latter, to evaluate different network design. Based on the literature exploration the framework is described in Chapters 5 and 6. The model development is described in Chapter 7. The case study analysis is described in Chapter 8. Finally the results and the conclusions are reported in Chapter 9.

2 Making decisions in logistics

Fierce competition in today's global market, the introduction of products with short life-cycles and the heightened expectations of customers have forced manufacturing enterprises, retailers and logistics service providers to invest in and focus attention on their logistics network. The imperatives of cost efficiency and responsiveness to customer demand have pushed firms to aggressively pursue the global location of production and distribution facilities, time-based competition, and a completely different organization of their logistics network. These strategies have dramatically transformed the way in which business activities are organized and carried out. Consequently, to reduce cost and improve service levels, logistics strategies must take into account the interactions of the various levels in the logistics network. In this chapter the dominant trends and pronounced developments in the logistics environment will be discussed as it has to be recognized that the impact of these developments on logistics can and have been considerable. The second part of this chapter is dedicated to the different decision-making processes in logistics and the different hierarchies that can be distinguished in these decisions. Finally, as we focus on the structure of the logistics network and the design of hub networks we will briefly discuss the different service network principles and the different hub network structures.

2.1 Trends in Logistics

Increased competition and marketing pressure dictate shorter *product life cycles* and lead-times, a larger variety of products, and production in smaller quantities. As a consequence, the logistics function has been undergoing dramatic changes in recent decades due to five primary factors. First and foremost the focus on customer service is one of the most dominant developments in logistics and has had a major impact on the organization of logistics networks. A second distinct factor has been the trend towards globalization, where materials and components are sourced worldwide, manufactured offshore, and sold in many different countries around the world. Closely related to globalization is the centralization and reduction of inventory that has been one of the most pronounced trends in logistics over the pas 30 years. A fourth trend has been the way in which time has become a critical issue in logistics. Product life cycles are shorter than ever, industrial customers and distributors require just-in-time deliveries, and end users are more demanding. A fifth trend is the fact that the capabilities of information and communication technology have created new logistics concepts. Collaboration is a sixth development we elaborate on, that perhaps will have the same impact on the way logistics is organized in the near future.

Customer service

So much has been written and talked about service, quality and excellence that there is no escaping the fact that the customer is more demanding, not just of product quality, but also of service. As more and more markets become in effect *commodity* markets, where the customer perceives little technical difference between competing offers, the need is for the creation of differential advantage through added value. Increasingly, a prime source of this added value is through *customer service* and may be defined as the consistent provision of time and place utility. In other words products have no value until they are in the hands of the customer at the time and place required.

There are clearly many facets of customer service, ranging from on-time delivery through to after-sales support. Essentially the role of customer service should be to enhance *value-in-use*, meaning that the product becomes worth more in the eyes of the customer because service has added value to the core product. Those companies that have achieved recognition for service excellence, and thus have been able to establish a differential advantage over their competition are typically those companies where logistics management is a high priority.

Globalization

Secondly, the flow of trade, capital, goods, and information has an increasingly international character. This is largely caused by the liberalization of world trade and the geographical specialization of production and therefore closely related to the development of centralization and reduction of inventory. As a result of the international competition, production processes have become more specialized and therefore an increasing part of the value added is placed outside the company's own facility. At the same time, we see a globalization of supplier and customer markets where domestic and local suppliers and customers play a less important role compared to global suppliers and customers. In other words companies compete more and more on a global level, where markets and production and distribution facilities are defined without regard for national boundaries.

Globalization therefore can be described as the integration of markets, nation-states, and technologies to a degree never witnessed before, in a way that is enabling individuals, corporations and nation-states to reach around the world farther, faster, deeper and cheaper than ever before, resulting in the spread of free-market capitalism to virtually every country in the world (Friedman 1999). The growth in world trade continued to outstrip the growth in most countries' GDP over the last fifty years of the 20th century (the Economist 2002).

Centralization and inventory reduction

In production and marketing processes, inventories serve as cushions to accommodate the fact that items arrive in one pattern and are used in another. However, the most prominent ongoing concern about inventories is cost. Inventories are carried as assets on a company's balance sheet. However, an increase in inventory cannot be automatically interpreted as desirable. A firm may manufacture much more than it can sell and excess inventories are often considered as waste. If this was the whole problem, then there would be no problem, as firms would keep inventory costs down by keeping inventories extremely low. However, being under-stocked and being repeatedly out-of-stock can also be expensive. One certain way to lose customers is to be an unreliable supply source. The solution, then, is to determine the proper balance of inventory and maintain it. Multinational companies operating in several European countries have tended to move towards a manufacturing system based on *Focused Factories* (Kotha 1996). In this case a plant is dedicated to a single product line or a relatively narrow range of products. Products as diverse as soap, electronic components and tires have all been subject to decisions to focus production in single plants. The multinational companies operating the plants then move products between countries in order to satisfy the demand in each national market (Bowen 1992).

In the same way that the advent of globalization has encouraged companies to rationalize production into fewer locations so too has it led to a trend towards the centralization of inventories. Making use of the well-known statistical fact that consolidating inventory into fewer locations can substantially reduce total inventory requirement, organizations have been steadily closing national warehouses and amalgamating them into internationally-operating distribution centers serving a much wider geographical area. For example, Philips has reduced its consumer electronics product warehouses in Western Europe from 22 to just 4. Apple replaced their 13 national warehouses with two distribution centers, reducing the number of stockholding points in their logistics network. In addition to these inventory savings, firms can also take advantage of economies of scale in warehousing. Although for many companies the centralization and reduction in inventory have been part of a broader response to growing global opportunities and increased levels of international competition, the pressure to achieve economies of scale has played an important role.

Lead-time reduction

Next to inventory reduction goals the need for *time compression*, and the way in which time has become a critical issue in management is one of the most visible trends in logistics. JIT manufacturing and distribution philosophy have reduced the size and increased the frequency of material movement. A series of new management principles and approaches, such as JIT (Hutchins 1988; Taylor 2001), quick response (Fernie 1994), lean logistics (Jones *et al*. 1997), agile logistics (Christopher 1998), and efficient consumer response (KSA 1993) have been developed over the past 20 years to help firms accelerate their logistical operations. Process and pipeline mapping techniques have been developed to analyze the expenditure of time in the supply chain and assess the opportunity for eliminating slack time and non-value adding activities (Ruijgrok 2001). This mounting pressure to compress time in logistics networks may seem at odds with the lengthening of the channels and links caused by globalization, in particular where these links cross international frontiers. Long transit times from distant production facilities can, after all, make the international supply chain slow to respond to short-term variations in demand and therefore increase the lead-time. The concept of logistics lead-time is simple: How long does it take to convert an order into cash? From the moment when decisions are taken on the sourcing and procurement of materials and components through the manufacturing subassembly process to the final distribution there are a complex of activities that must be managed if customers are to be gained and retained. The order lead-time of these processes has been steadily decreasing. A.T.Kearney (1999) estimated that within Europe they have declined on average from 27 days in 1987 to 12 days in 1998. Without exception, all industries display a sharp reduction in the time consumed in the supply chain (Muilerman 2000).

Information technology

Finally, the capabilities of information and communication technology (ICT) have created new logistics alternatives and opportunities. Information systems are now available to support production and distribution decisions. Real-time communications can be established with vendors and customers through electronic data interchange (EDI). The rapid development of ICT is one of the key factors influencing the structure and performance of supply chains (Fox 1987; Fisher 1997; Colony 2002). The increased availability of sophisticated information technology is bringing change to the way volume is managed in the operating stream, affecting the creation of fundamental economies of scale and density. It alters the question of intermodal coordination, by making it possible to monitor and even control shipments door-to-door, improving hands-off processing and mitigating their effects. UPS stated that it is no longer a trucking company with technology, but rather a technology company with trucking. The rapid pace of change of business processes brought about by information technology development can be legitimately termed a revolution.

In the logistics sector information technology has been a source of significant productivity gain, and the catalyst for industry restructuring. Important developments in information and communication technology are: (1), shipment and asset-tracking technologies, such as mobile communication for field personnel (cellular phones, two way radios, on-board computer systems), passive asset-tracking and monitoring systems (satellite and mobile tracking systems), and bar codes and radio tags (RFID), (2) routing and dispatch optimization models; operations research software is now able to manage and reconfigure routing, matching, blocking and consolidation decisions, and (3), commercial transaction management software, such as marketing software that is able to re-price and manage yields in response to differential costs and supply/demand relationships.

Partnerships, alliances and collaboration

To comply with these changes in the environment that seem to occur ever faster companies are turning towards coordination, partnerships, and supply chain management. Examples of companies that specifically aim to respond quickly to market demand are Zara, with its fashion products, Dell with laptops and personal computers, Nokia with mobile phones, and it seems that the product's life-cycles become ever shorter. In anticipation of these developments companies are increasingly looking beyond their own firm boundaries. For many business exchanges the emphasis on relational exchange has brought about greater communication, coordination, and planning between partners. Since the early 1990s, there has been a growing understanding that supply-chain management should be built around the integration of trading partners. Christopher (1998) proposes that today's business is increasingly 'boundary-less', meaning that internal functional barriers are being eroded in favor of horizontal process management and the external separation between vendors, distributors, customers and the firm is gradually lessening. The first robust initiative created to enable integration in the supply chain dates back to 1992, when 14 trade association sponsors, including Grocery Manufacturers of America - a food marketing institute - created a group named *Efficient Consumer Response Movement*, or *ECR*, with the purpose of leading an unprecedented transformation in business practices (Robins 1994). A number of other collaborative-based initiatives are worth mentioning; *Vendor-Managed Inventory* (VMI) and *Continuous Replenishment*

(CR) are coexisting supply chain techniques that, in different ways, try to deliver the promised benefits of ECR. VMI was adopted by many companies in different business sectors and, according to Cooke (1998), two of the first companies to put the theory into practice were Proctor and Gamble and Wal-Mart, in the USA. This partnership gave impetus to the diffusion of VMI within the grocery sector, at a pace quicker than has been observed in other sectors (Peck 1998). A typical example in the Netherlands is Heineken and Albert Heijn.

Following its emergence in 1995, *Collaborative Planning, Forecasting and Replenishment* (CPFR) has won the support of companies in the drug, grocery, general merchandise, and apparel industries (Blair 1998). According to Cooke (1998), five companies, Warner-Lambert, Wal-Mart, SAP, Manugistics and Benchmark Partners initiated the first CPFR project. Other examples since then are Compaq and Trading Partners, New Balance and Selected Retailers, GM and dealers, Kimberly-Clark and Kmart, Hewlett-Packard and Wal-Mart, Lucent and Wal-Mart, Sara Lee Apparel and Wal-Mart, and Mitsubishi and dealers. We will address collaborative initiatives in more detail in Chapter 3 and will focus there on the scope and characteristics of collaboration in detail. We will first discuss, however, the decision-making processes in logistics.

2.2 Decision making in logistics

Seen from a business perspective, collaboration is never a goal to be reached, it is merely a means to an end. The business strategy determines the logistics strategy and in turn, decisions need to be made concerning outsourcing, collaboration or in-house solutions.

Business logistics, however, which, according to our definition the entire process of materials and products moving into, through and out of a firm, has taken on an increasingly important role in today's business. This interest arises from several sources, internally and externally, as illustrated by the previous section of this chapter. For example, the implementation of a flexible production system radically alters the economies of scale and scope and may consequently affect not only production and shipment sizes, but also location decisions. Business logistics interacts intimately with planning and marketing; the management of inventories, of raw materials, and intermediate products must be coordinated with production plans to minimize combined inventory, transportation and out-of-stock costs. Marketing, logistics and production planning jointly determine sales regions, prices, and the plant-specific production quantities that maximize profits. Effective logistics management must therefore deal with a wide range of decisions that have been categorized by different authors based on the scope, the investment required, the time horizon and the frequency of the decision involved. Before we address the key aspects of collaboration, focusing on modeling decision-making in logistics, we first need to classify the different levels of decision-making, and to position the different business and logistics strategies. In this section we present a framework, based on the literature, for viewing the different types of decisions relevant for the logistics network design and this framework will again be used to classify the scope of collaboration in Chapter 6.4. Firstly, we will discuss the hierarchy, unmistakably present in business and logistics, influencing the decision-making and choice behavior we focus on in this dissertation.

2.2.1 The business strategies

At the top of the decision-making hierarchy is the business strategy, which determines all of the strategic, tactical and operational aspects of the logistics networks. Just as the firm chooses an appropriate strategy to accomplish its objectives, the choice of a strategy leads to decisions of a more tactical or operational nature which will flesh out the strategic concept and guide the activity of the firm on a daily operational basis. Lalonde and Masters (1994) define a business strategy as a tool to accomplish the fundamental objectives of the firm. In this sense the firm's strategy is secondary and is very much a means to an end. Copacino and Rosenfield (1987) and Magee *et al.* (1985) define a business strategy as a choice of products, markets and required service levels. Stock *et al.* (1998) define a business strategy as the set of decisions that specify how a business company will achieve and maintain an advantage within its industry. These strategic choices are then translated into more operational objectives and therefore affect sourcing, production and logistics processes (Chow *et al.* 1995). According to Vermunt and Binnenkade (2000), the business strategy is used to position the company in what is called the *value discipline matrix*. Companies cannot offer all kinds of products to all people. They must find a unique value that they alone can deliver to a chosen market. The strategy that is then formulated should be adopted by the company to guide business management and supply chain execution decisions (*responsiveness* and *reliability*). The main strategic options or value disciplines, according to Treacy and Wiersema (1997), are operational excellence, product leadership and customer intimacy.

Factors of great importance, that set the requirements for logistics decision-making concern production and marketing (Emerson and Grimm 1996; Morash *et al.* 1997). On the one hand, the requirement of the production department can be expressed as production cost reduction and efficiency gains through large production lot sizes or responsiveness through small production lot sizes. These requirements obviously call for different logistical responses. On the other hand, logistics requirements, stemming from the marketing department, generally concentrate on achieving maximum customer satisfaction. This has implications for the speed of delivery, degree of customization, etc. (Wu and Dunn 1995).

This link between marketing and logistics has been acknowledged for almost a century (Shaw 1912; Weld 1916; Mentzer *et al*. 2001; Chandra and Kumar 2000; Levy and Grewal 2000; Lings 2000). Bartels (1976) even argues that marketing and distribution are not separate activities. The credit for the emphasis on customer service in business strategy must go to Michael Porter, who through his research and writing on the concept of the value chain and the emphasis on either customer value or cost efficiency (Porter 1980; 1985) has convinced managers and strategists of the central importance of competitive relativities in achieving success in the marketplace. As it becomes clearer that the business strategy has major consequences for business logistics, it is apparent that through customer service market share could be gained and the only way to achieve this is through changes in logistics performance and, thus, more and more attention has been given to logistics. Strategy experts argue that the profits a company can hope to make basically depend on two variables: its stance in comparison with its competitors (actual and potential) and its position vis-à-vis its suppliers and customers (Porter 1980). The reason is clear; if a firm cannot offer anything special that it's competitors do not have, it's margins shall disappear through competition. But carefully watching one's competitors is not enough. A company is just one step between its suppliers and customers. It seems that a company must be constantly on the look-out, not only for its competitors, but also for its suppliers and customers, who are always trying to keep the largest possible portion out of the total value being created. A successful company will, therefore, be that which obtains an unassailable competitive advantage over its competitors, its suppliers, and customers: *success through competition*. Some highly successful companies do not, however, share this all-encompassing competitive view of the world. They do not compete against everybody, but rather pick their fights carefully and turn many potential competitors into powerful allies. For these companies, cooperation becomes the strongest competitive edge, as we have seen by the examples of collaboration in the previous section.

2.2.2 The logistics strategies

It will be apparent from the previous comments that the mission of *logistics* is to plan and co-ordinate all those activities necessary to achieve the desired levels of service and quality at the lowest possible cost, as defined in the business strategy. Logistics must therefore be seen as the link between the marketplace and the operating activity of the business (Christopher 1998). The common way of depicting logistics choice behavior is to position logistics choices within a hierarchical model. The tenet of the existing models is that lower-level logistics decisions are conditional upon higher-level decisions. The purpose of such a hierarchical categorization is twofold. First, it is consistent with how an organizational structure operates within a firm, where each level of the organization deals primarily with one of the levels of decisions outlined above. Secondly, the separation of the overall decision-making process into various levels makes the planning, design, and operation of a logistics system tractable. It should be noted, however, that inter-dependencies exist, not only among decisions within any given level, but also between decisions at different levels. Higher-level decisions often determine the boundaries for decisions in subsequent levels. On the other hand, evaluating higher-level decisions requires the consideration of the expected outcome of lower-level decisions. Anthony (1965) categorized business decisions, resulting in three classes: strategic, tactical and operational decisions. For each class of business decisions many models aiming to support the decision-making process have been developed. Christopher (1994) presents a hierarchical model where customer service requirements play a decisive role. Customer service requirements set the standard for lower-level logistics decisions. Four levels are distinguished: strategic decisions (customer service), structural decisions (network strategy, channel design), functional (warehouse design, materials management) and decisions concerning implementation (information systems, facilities and equipment).

Ruijgrok (1994) takes a broader view, where, in addition to customer service characteristics, environmental factors (e.g. technology and infrastructure), product, market and company characteristics of the logistics organization are seen as an intrinsic part of the logistics decisions. Vermunt and Binnenkade (2000), with their logistics framework presented three levels of activities: resources layer, information layer and the business layer that interacts with both other levels. According to Copacino and Rosenfield (1987), the development of a logistics strategy is based on the overall business goals and strategies, although the execution of this strategy is however, based on the logistics planning and logistics decisions. The process for developing a logistics strategy is outlined in Figure 2-1 and commences with an understanding of the corporate goals and strategy formalized in the business strategy. Next, the business strategy has to be translated into customer service requirements. Ideally all logistics strategies and systems should be devised in the following sequence: (1) analysis of customers' needs leading to a definition of customer service objectives, and (2) customer service objectives then become the focal point around which logistics systems must be designed. The implementation of this logistics strategy requires decisions on different aspects of logistics (i.e. facility location, inventory management, delivery frequency, fleet management, etc.). A selection of different aspects is illustrated in Figure 2-1.

Business and Logistics strategy

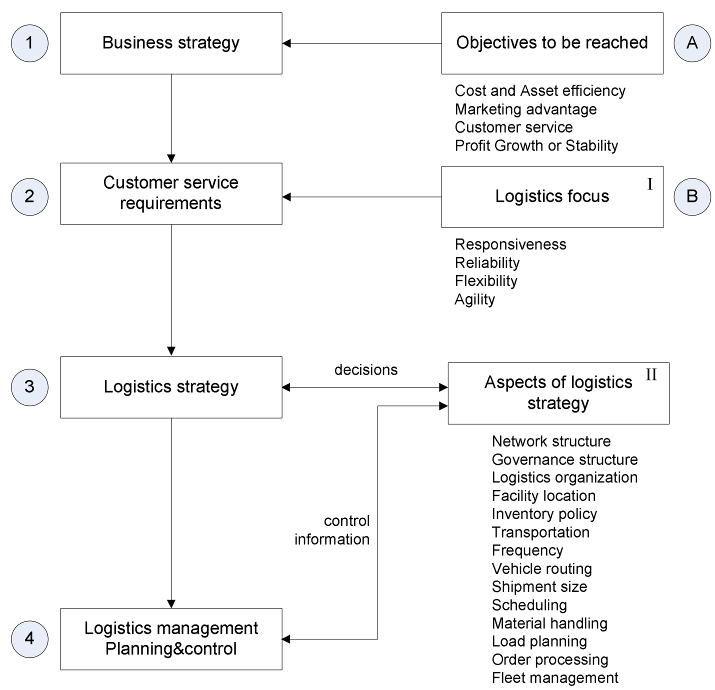

Figure 2-1 : Development and aspect of a logistics strategy. Based on Copacino and Rosenfield (1987).

I) The logistics focus is closely related to the business strategy.
II) This is no comprehensive list of all aspect of the logistics strategy but merely a selection to illustrate the wide range of decisions and choices.

Once the logistics strategy is formalized and implemented through the logistics network design, control over the flow of goods and information through the network has to be arranged. The control and planning is illustrated by the logistics management in Figure 2-1. Copacino and Rosenfield (1987) divide the logistics system design decisions into four hierarchies or levels: (1) long-term distribution and production patterns, this highest level in logistics decisions involves plants and warehouse choices, customer assignment, and product assignments to facilities, (2) deployment of inventories within the logistics network, (3)

aggregate planning for the intermediate term, and (4) plant and warehouse operations, where specific manufacturing and distribution plans for each operational period are determined.
Based on Ruijgrok (2001), where a similar hierarchy is presented, we categorize logistics decisions into four levels, based on the scope, the investment requirements, and the time horizon and frequency of the decisions involved.

(1) *The structure of the logistics network*: this first level of decision making concerns decisions on the number, size and locations of the fixed facilities in the network and the assignment of customers and production to these facilities. In brief, it is the design of the entire path from suppliers to customers. These decisions can be characterized as *strategic decisions* and are usually concerned with major capital commitments and the efficient allocation of resources to the various components of logistics operations over a relatively long period of time and thus determine the network through which production, assembly and distribution serve the marketplace. Decisions concerning the structure of the logistics network may deal with a relatively long planning horizon of, say, 2 - 5 years since long lead times are required to construct plants and install processing equipment. A relatively high level of uncertainty may be associated with demand, political environments, and exchange rates over such a long planning horizon.

(2) *Alignment of the logistics network*: At this second level decisions are made concerning the alignment of the network. For example, decisions about the inventory levels, locations and safety stock are taken at this level and typically deal with moderate capital investments and involve plans for annual, semi-annual, or seasonal time horizons. Decisions at this level can usually be reversed at lower cost than that which is required to reverse strategic decisions. The alignment of the network prescribes material flow management policies, including production levels at all plants, assembly policy, inventory levels and lot sizes. It is important to determine a measure of customer service that can be expected to give results at the tactical level and provide this as feedback to the strategic level in order to improve customer service by providing a more responsive network design. These decisions prescribe material flow management policies but are limited by the network made available by structure-related decisions. These decisions deal with a mid-range horizon of, say, 6-24 months.

(3) *Scheduling of the logistics network*: at this level decisions are made on the scheduling aspects of the logistics network. For example, what should the delivery frequency of the replenishment be and of what shipment size. The scheduling of the logistics network prescribes the frequency of delivery, shipment sizes, and lead times. Decisions concerning the mode-choice and transportation management are also taken at this level. The trend towards time-compression in the logistics network has had major consequences on this level of decision-making. Due to the increased attention to time in the network, the scheduling of the logistics network and its reliability, time windows and frequency have become a very important issue. Time horizon of these decision are usually 3 to 30 days.

(4) *Resource management*: finally, at the fourth level, decisions about the resources and the efficient and effective deployment of these resources are taken. For example, decisions concerning vehicle routing, load planning, order handling, and order picking are made at this level. These kinds of decisions are often referred to as *operational decisions*, and they deal with day-to-day operations; they are characterized by low capital investments and can be reversed at relatively low cost. Typical decisions concern the vehicle routing, the load planning, driver scheduling. Time horizon of these decisions ranges from 2 – 48 hours.

This last categorization will be used in this dissertation. However, we will focus on the first level, the structure of the network, in terms of locating hubs, the number of hubs, the connections between the hubs and the capacity required. In order to derive the logistics costs accurately it is necessary to incorporate the other three levels; the alignment, scheduling and resource deployment.

2.3 Focus on network structure

Before we proceed with a discussion on collaboration in logistics networks we will first briefly discuss our focus on the structure of the network and present some background to logistics networks. Basically there are distinct streams of research that have been influential in the development of the concept of supply networks: (1) the largely descriptive research on industrial networks conducted by researchers within industrial marketing and purchasing, and (2), the more prescriptive research on supply chain management, based in the fields of strategic management, operations management and logistics. Researchers within the first group have developed conceptual models to provide a better understanding of business markets in terms of the nature of buyer-supplier relationships and the embeddedness of these in "industrial networks", modeled as inter-connected actors, activities, and resources (Håkansson 1982, 1987; Håkansson and Snethota 1995). The term supply chain management was originally used in the early 1980s (Oliver and Webber 1992; Houlihan 1984) to refer to the management of materials across functional boundaries within an organization but was soon extended beyond the boundaries of the firm to include upstream production chains and downstream distribution channels (Womack *et al*. 1990; Womack and Jones 1996; Christopher 1992).

In the first chapter we presented the three-layer network model. There are three categories of networks that can be considered: (1) the actor network, (2) the service network, such as the parcel network of UPS, the freight network of DHL, or the rail shuttles offered between Rotterdam and the Ruhr, and (3), infrastructure or physical networks, such as road or railroad networks. A transport service network is, of course, always related to a physical network. A logistics network consists of a succession of basic transport (transfer), collection, distribution, and inventory activities. Logistics service providers operate either on their own or in a joint effort with others and operate in logistics service networks. These service networks have both spatial and time dimensions. In its simplest form, direct distribution, the service networks' starting points are directly linked to destination points without intermediate actions. Direct distribution cannot, therefore, be combined with other services. In 'indirect distribution', for efficiency reasons, distribution channels are combined, and thus goods are grouped and ungrouped in distribution centers and are transferred between those centers. In

Chapter 1 (Figure 1-8) we presented the network activities we distinguish in the service network and from these basic elements we will form different network configurations, each rendering specific advantages and disadvantages with respect to the physical distribution channels they have to accommodate. First we will discuss some elementary network characteristics.

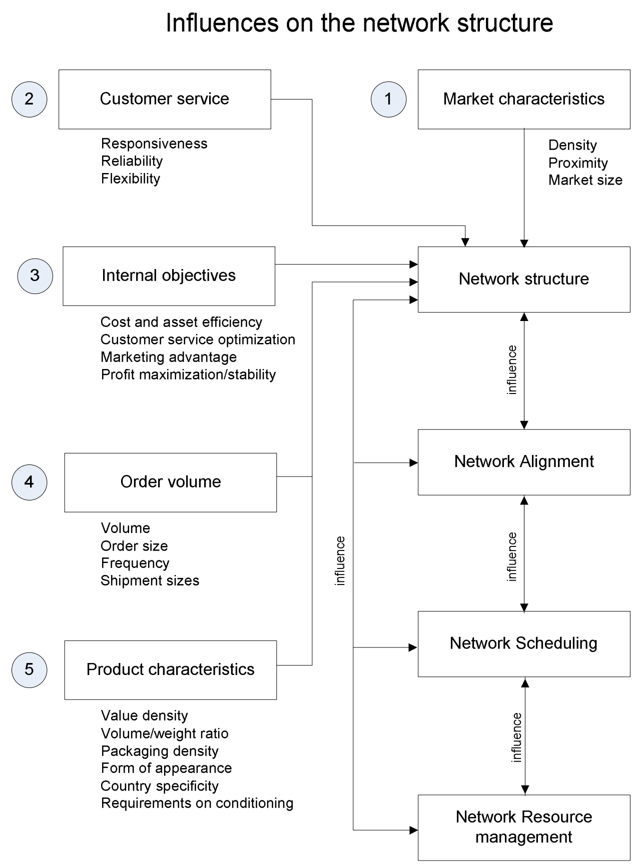

Figure 2-2: Variables influencing the logistics network configuration

The main focus of this thesis is the service network, especially hub networks, and the characteristics of these networks can be seen from two points of view: that of the network user and that of the service provider. In the context of logistics networks the main characteristics of any service network from the user's point of view are costs, reliability, and shipment time, determined by network characteristics such as space accessibility, time accessibility, network speed, and reliability (Van Nes 2002). For the user the *Space Accessibility* - the number and distribution of access points where the user can enter and leave the network - is very important. In this context, typical examples are airports, container terminals, motorway ramps, and inland ports. A second characteristic is *Time Accessibility*: the distribution of opportunities per unit of time for the user to use the network. In the logistics context this would be for example the delivery frequency or the number of stops. A third characteristic is the *Network Speed* of the network the determinant of the shipment time. Finally, the fourth characteristic we distinguish is the *Network Reliability*: in this thesis network reliability is explicitly included in the description of the network as network quality in terms of reliability is a very important factor in logistics. From the point of view of the service provider or operator it is evident that costs and revenues are the main service network characteristic. First of all we distinguish the *Investment Costs*, for example the costs of building terminals, stock-points or cross-docking facilities; investing in the vehicle fleet; or the information technology. Secondly, the *Maintenance Costs*, the costs for maintaining the quality of the network, vehicles and facilities. Finally, we distinguish the *Operating Costs.* These costs are especially related to the transport services, handling operations and administration. These costs are determined by, for example, the length of the transport service network, the fleet size, and the frequency with which these services are offered.

In section 1.2 we presented the different activities distinguished in the network that will be used to determine the costs in the logistics network. These characteristics for considering a service are the shipment time, which is primarily determined by network characteristics such as space accessibility, time accessibility, network speed, and reliability. Thus, when designing a network from the user's point of view it is important to take these requirements into account.

2.4 Discussion

In this chapter we discussed some dominant trends and pronounced developments in the logistics we have seen that the impact of these developments on the logistics decision-making processes can and have been considerable. We elaborated on these developments because the impacts these developments in manufacturing, trade, techniques, and the environment can have on the logistics structure are enormous. For example the emergence of the internet and the possibility to order everything from books, clothes, to electronics online has led to a considerable increase in parcel-delivery services and the use of vans. An issue that, until now did not receive very much attention in business and logistics literature, is sustainability. The level of sustainability could well become a third objective of companies; not only from a marketing point of view but also from a cost point of view. The legislation that is being prepared and current on pollution and air quality can have enormous impact on the way business and logistics is organized, as can the increasing fuel prices. We did not explicitly incorporate these external costs, although possible to do so, we only include costs for logistics activities and transaction related costs.

In the second part of this chapter we discussed the different decision-making processes in logistics and the different hierarchies that can be distinguished in these decisions. The four levels we distinguished in this hierarchy will be used often in the remainder of this dissertation; not only in our modeling framework but also when we classify the different types and scopes of these collaboration initiatives. The business and logistics strategies we discussed in this chapter will be extended as we will introduce collaboration as specific strategy in doing business and logistics.

3 Collaboration in logistics networks

Alliances, partnerships and collaboration among companies are a fact of life in business today in which the strategic competitive advantages to be gained by adopting a supply chain approach to business are widely recognized (Cooper and Elram 1993; LaLonde and Masters 1994; Mentzer *et al.* 2001a). Nix (2001) explains that a managed supply chain environment usually begins with collaboration with immediate trading partners and possibly evolves to a supply chain with additional tiers. Rackham (2001), states that: "*successful partnerships are about radically redesigning a business relationship ..(and) partnership creates new value that cold not be achieved within the existing vendor/customer roles*". Consequently, many recent professionals have focused on prescribing how partnerships can be best achieved (Rackham 2001; Kador 2000) or how existing relations can be strengthened (Kerns 2000).

Traditionally, most organizations have viewed themselves as entities that exist independently from others and which indeed need to compete with them in order to survive. There is almost a Darwinian ethic of *survival of the fittest* driving much of corporate strategy. However, such a philosophy can be self-defeating if it leads to an unwillingness to cooperate in order to compete. Behind this seemingly paradoxical concept is the idea of collaborative networks. As we discussed earlier in Chapter 1, the term *collaboration* has taken on several interpretations when used in the context of supply chain management and common to many of these descriptions is a long term relationship between partners that work together. Based on Schrage (1990), we defined collaboration as an affective, voluntary, mutually-shared process where two or more departments work together, have mutual understanding and a common vision, share resources, and achieve common goals. Key dimensions are a cross-organizational scope, a commitment to working together, and some common bond or goal.

The decision to take part in a collaboration is a key decision in logistics, and depending on the scope, can have a far-reaching impact on a company. *Transaction Cost Analysis* (TCA) helps in finding this so-called *Efficient Boundary* by providing insight into the trade-off between production and governance costs. TCA forms an important part of our framework and therefore we will discuss this approach in detail. Before we do so, we will first discuss the different theories, as reported in the literature, that deal with the relationships and partnerships between firms. In section 3.3 the different types of collaboration are discussed. In section 3.4 the drivers and decisions to collaborate are discussed. In section 3.5 we consider the firm in its network context and therefore introduce the notion of dominance, while the transaction costs perspective stresses the efficiency benefits from reducing the governance costs of transaction, a network approach allows consideration of the strategic benefits from optimizing not just a single relationship but the firm's relative network position and relations. It is therefore important to assess the position of the firm in relation to its buyers and suppliers. Finally, this chapter is concluded with a discussion of the implications of the presented Transaction Cost Analysis, drivers and barriers, and decision-making framework on the remainder of the research and design methodology.

3.1 Relations and partnerships

Why partnerships are formed may be considered from different perspectives. Cooper and Gardner (1993), distinguish six representative, though not exhaustive views on the formation of collaboration from a marketing and logistics perspective. They distinguish: (1) *Transaction Cost Analysis* (Williamson 1985), (2) *Dependence Balancing* (Heide and John 1988), (3) *Buyer-Seller relationships* (Dwyer *et al.* 1987), (4) *JIT relationships* (Frazier and Speckman 1988), (5) *Power-Conflict theory* (Gaski 1984), and (6) *Franchising dynamics* (Stern and El-Ansary 1992).

Williamson (1975;1981;1985) discusses three primary determinants of transaction cost magnitude: specific assets deployed, uncertainty, and frequency. The interaction between these three determinants is most powerful in driving the need to approach vertical integration or collaboration.

Heide and John (1988) add dependence balancing to the traditional transaction cost approach. A firm with more specific assets committed to the relationship is more dependent on the relationship for its success. The level of dependency is also affected by the number of exchange partners available and the concentration of exchanges. Offsetting investments can balance dependence and safeguard specific assets. If dependence is balanced, each party makes itself equally irreplaceable to the other. Dwyer *et al.* (1987) suggest that the formation of some relationships is buyer-motivated, while others are seller-motivated. The costs and rewards of the overall relationship are balanced against other available alternatives. Frazier *et al.* (1988) suggest a model to predict when just-in-time relationships are appropriate. Their political economy paradigm includes part-material characteristics and end-product characteristics as predictors. In the logistics context, part material variables might be a modal selection or a needed replacement part. The resulting end-product would be customer service levels. JIT systems typically require close relationships between suppliers and customers. Gaski (1984) summarizes the theory of power and conflict in channel relationships. The power one party may have over the other can be coercive, non-coercive, countervailing exercised, or unexercised. A conflict resolution model relates satisfaction and performance to power and conflict variables. Stern and El-Ansary (1992) discuss many kinds of channel relationships. Franchising represents one of the closer associations, involving contracts purchase agreements, advertising spending, and centralized planning. In return for being part of such a structured arrangement, the franchisee benefits from the franchiser’s image and reputation.

Verduijn (2004), who focuses on switching between actors due to turbulence in the business environment, distinguishes four different approaches in inter-organizational relationships next to Transaction Cost Analysis: (1) *Structural embeddedness*, (2) *Agency Theory*, (3) *Resource Based Theory*, and (4) *Resource Dependency theory*. All of which describe different types of inter-organizational relationships and the motivations for organizations to select a specific governance structure and thus relevant to our network design approach. *Structural embeddedness* refers to the fact that economic action and outcomes are affected by the actors' dyadic (pair-wise) relations and by the structure of overall network relations (Granovetter 1992). Examining exchanges between dyads, "without reference to the nature of other ties in the network or how they fit together", cannot show adequately how the network structure influences exchanges. *Agency theory* is the second major stream of thought in organizational economics, apart from TCA and occurs whenever a partner in a transaction delegates authority to another (agent) and the welfare of the partner is affected by the choices of that agent (Barney and Hesterley 1996). *Resource based theory of the firm* attempts to explain why one firm performs better than other firms in the same industry. As the name of the theory indicates, the real sources of a firm's success are due to the organization's firm-specific or idiosyncratic resources and capabilities.

Resource dependency theory is based on power and the ability of a firm to maximize their power (Aldrich 1979; Pfeffer and Salanick 1978). Within this perspective, organizations are viewed as coalitions, altering their structure and patterns of behavior to acquire and maintain needed external resources. From our network design perspective it is important to identify those aspects of collaboration and the relationships between firms that affect the network structure and influence the decision to participate. In Chapter 6 we will present our network design framework for collaborative networks that makes it possible to classify the collaboration and the scope of the collaboration. Therefore, we will focus on the fundamental aspects of collaboration that influence logistics network design, and can be incorporated in a modeling framework.

3.2 Transaction costs and collaboration

Transaction costs analysis is concerned with the minimization of the sum of production and governance costs. Production costs are the costs for producing the product or service (wages, materials costs, equipment, etc.), while the governance costs represent both the bureaucratic costs of internal governance and the corresponding governance costs of markets, i.e. transaction costs. Williamson (1975; 1981; 1985) presented a framework to analyze the costs mentioned above, which is based on economics, organization theory, and contractual law literature. The basic unit of analysis of transaction cost economics is the transaction laid down in a contract between two trading parties. According to the transactional view, a transaction can take place in the institutional framework of the market (using the price mechanism), or of a hierarchy (which requires a co-ordination of efforts), whatever allows it to be executed most efficiently (Kleas 2000; Williamson 2005). It is assumed that the most efficient mode, for a particular kind of transaction will prevail.

Williamson uses human factors such as bounded rationality and opportunism. Opportunism is considered to be an inherent human tendency which, unless bridled by competitive market structures or highly measurable performance in predictable environments, will cripple market-based exchange. Bounded rationality arises due to the difficulty facing human agents of replicating a perfectly functioning market. Williamson (1975) states that the goal of economic organization is: "*to organize transaction so as to economize on bounded rationality while simultaneously safe-guarding them against the hazards of opportunism*". One of the main questions posed in the transaction costs approach is whether a firm should *make* or *buy*. The firm's production costs, transaction costs as well as governance costs are considered when different governance costs are considered. The governance costs represent both the bureaucratic costs of internal governance and the corresponding transaction costs (i.e. governance costs of markets). The objective is to minimize the sum of the governance and production costs by choosing an appropriate governance structure, market or hierarchy or some hybrid form.

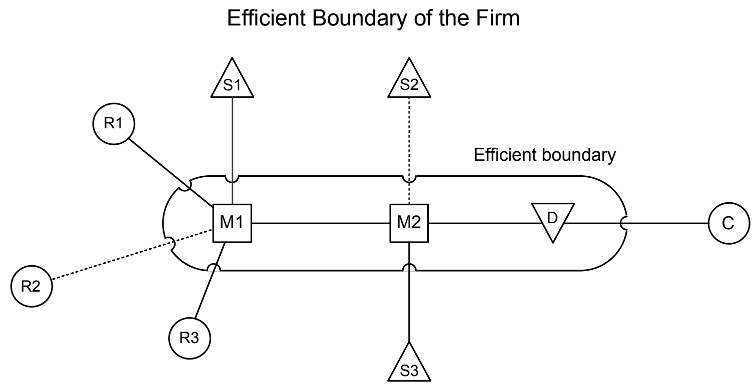

Figure 3-1: Efficient boundary of the firm

Transaction costs are seen as costs for negotiating, making contracts, and are based on five distinctive cost drivers. Two of these (*bounded rationality* and *opportunism*) are related to human behavior and the three remaining drivers (asset specificity, uncertainty and frequency) are related to the dimension of the transaction. Williamson (1975) discusses three different transaction costs categories: (1) information cost, (2) bargaining cost, and (3) enforcing cost. These costs can be divided in ex ante and ex post types. *Ex ante* transaction costs consist of the costs for drafting, negotiating, and safeguarding an agreement. The *ex post* costs consist of mal-adaptation, haggling, setup and running of the governance structure, and the bonding costs of effecting secure commitments. The treatment of *efficient boundaries* in this section deals only with a part, although an interesting part, of the full set of organizational issues. Only two organizational alternatives are considered: either a firm makes a component itself or it buys it from an autonomous supplier. Thus mixed modes, such as franchising, joint ventures, etc. are disregarded in this example. I also take the core technology as given and focus on a single line of commerce, say the activities of a particular manufacturing division within a larger industrial enterprise. The object is to describe how the economizing decisions which define the outer boundaries of this division are made.

Suppose that there are two distinct production stages in the logistics network, represented by M1 and M2 and draw these as squares. Let raw materials be represented by R1, R2 and R3 and draw these as circles. Let component supply be represented by S1, S2 and S3 and draw these as triangles. Let distribution be denoted as D. Finally, let a solid line between units represent an actual transaction and a dashed line a potential transaction, and draw the boundary of the firm as a closed curve that includes those activities that the firm does for itself. The closed curve that defines the efficient boundary of the firm in Figure 3-1 includes, in addition to the primary manufacturing activities, distribution D1. Raw materials R1 and R3 and components S1 and S3 are procured in the market. Obviously this is arbitrary and merely illustrative. It also oversimplifies greatly. It is relatively easy, however, to elaborate the schema to add to the core, to consider additional components, to include several material stages and consider collaboration, to breakdown distribution etc. At the risk of oversimplification,[5] the essence of the foregoing argument can be shown graphically by expressing both production cost differences and governance cost differences as functions of asset specificity (φ).

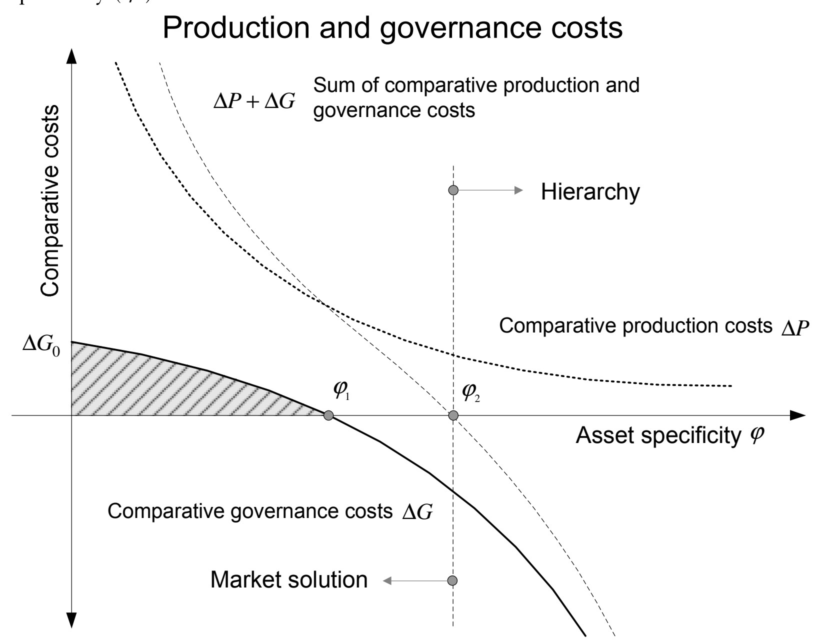

Figure 3-2: Comparative production and governance costs (e.g. the difference between in-house and a market solution). Adapted from Williamson (1985).

Thus let $\Delta P = f(\varphi)$ be the production cost difference between the internal organization and the market, $\Delta G = g(\varphi)$ be the corresponding governance cost difference, and assume that these two functions have the shapes and relative locations shown in Figure 3-2. So long as the vertical sum of $\Delta P + \Delta G$ remains positive, market procurement enjoys the advantage. Indifference between governance structures obtains where $\Delta P + \Delta G = 0$, namely, at φ_2 . Internal procurement enjoys the advantage for values of φ that exceed φ_2 (since $\Delta P + \Delta G < 0$ in this region). As goods and service become very close to unique (i.e. φ is high in Figure 3-2), economies of scale will no longer be realized when ΔP asymptotically approaches zero. The production cost penalty for using internal organization is severe for standardized transactions for which market aggregation economies are great and where φ is low. However, the objective is to minimize the sum of the comparative costs of governance and production, as depicted in Figure 3-2. Williamson (1985) argues that the firm will never integrate vertically for production cost reasons alone, such a decision is more often explained

[5] The main simplification is that ΔP (and possibly ΔG) is also a function of the amount produced. Figure 3-2 can be thought of as a cross-section for a fixed level of output. Furthermore, the optimal value of φ will depend on both demand effects and absolute costs effects.

by transaction cost economies. The basis for the discussion of production costs in the transaction costs approach is economies of scale. When outsourcing or collaboration in logistics is discussed, the focus is often on the costs of the logistics operations. One reason to expect lower costs is the fact that a service provider is often able to achieve economies of scale by providing logistics services to a number of clients (Fernie 1989; Lalonde and Cooper 1989; Bardi and Traci 1991, Anderson). When there is a low degree of asset specificity outsourcing or collaboration could be beneficial due to the ability to achieve economies of scale, aggregate uncorrelated demands and thereby realise risk-pooling benefits.

In Figure 3-2, ΔP represents the difference between the bureaucratic cost of governance and the transaction costs. If only the transaction costs are studied, market procurement is the preferred supply mode where asset specificity is low, because of the incentive and bureaucratic disabilities of internal organization in production cost control aspects. These transaction costs would be zero if humans were honest and possessed unbounded rationality but as this is not the case, it becomes important to examine more carefully some important dimensions of transactions. Of the three attributes (asset specificity, frequency and uncertainty), asset specificity is generally accepted to be the most important, and refers to the situation where both the firm and/or the selected supplier(s) need to engage in specific investments and develop proprietary know-how to make transactions possible. It is therefore crucial to include the asset specificity of all participants when designing logistics networks. For example, if highly specialized equipment is needed to ensure quality for a unique customer, the service provider will be reluctant to invest in such an initiative without safeguards.

Transaction costs arise when goods and service are transferred across technologically separable phases of production or distribution (Williamson 1985). How costly the process of transferring is depends on the governance structure being used, i.e. the way this process is organized. What reasons make trade incur costs? An intuitive guide is given in Coase (1960): "*In order to carry out a market transaction it is necessary to discover who it is that one wishes to deal with, to inform people that one wishes to deal and on what terms, to conduct negotiations leading up to a bargain, to draw up a contract, to undertake the inspection needed to make sure that the terms of the contract are being observed, and so on".* Taking Coase's lead, Dahlman (1979) summarizes the key items of transaction costs according to the different phases of the transaction. In the pre-contracting stage the costs incurred are mainly the search and information costs. In the second stage, the contracting stage, costs for bargaining and negotiating are incurred. In the third stage, the post-contracting stage, policing costs of enforcement can be distinguished.

As a result, according to Dahlman (1979), transaction costs are rooted in lack of information. For getting over the incompleteness of information, both sides of buyers and sellers have got to locate suitable trading counterparts, formulate acceptable decision criteria, negotiate for better terms and ensure the realization of *ex ante* promises. All these efforts involve not only real resource consumption, like telephone bills, information subscription fees, transportation fees, hourly wages, but also the opportunity costs of time spent. In principle, the costs of increasing the available information would be worthwhile if the quality of the decision can be sufficiently improved. And the extent of these costs will affect the efficiency of the market relative to the hierarchy. The resources needed to overcome the gap in information are also referred to as the *First Round* of information problems.

3.2.1 Asset specificity.

Asset specificity is the degree to which investments are specific for a certain relation. It is viewed as the most important factor. It refers to the situation where both the firm and/or the supplier need to engage in specific investments and develop proprietary know-how to make transactions possible. There is a trade-off between the cost savings and the risk due to the assets' non-salvageable character. Dedicated investment will often permit production costs reductions but these investments also involve risks. The higher the grade of *asset specificity* a relation has, the more costly it is to change providers. Four types of asset specificity can be distinguished:

(1) *Site specificity*, can be explained by an asset immobility condition, which means that the set-up and/or relocation costs are very high. Once such assets are located, the parties thereafter work in a bilateral exchange relationship.

(2) *Physical asset specificity*, can be explained by specific assets used for a specific task in the relation. For example, when a service provider invests in a dedicated vehicle fleet.

(3) *Dedicated assets*, i.e. specialized equipment to perform a specific task on behalf of a particular buyer.

(4) *Human asset specificity*: is due to learning by doing and can be described as the necessary investment in knowledge, ability and relationships between persons, and in terms of the degree to which they are specific for the relationship.

The four types listed above make up the total asset specificity we distinguish, and form an important factor in determining the decision to participate. We use transaction costs to determine the asset specificity of the potential participants when joining a consortium and to what extend these potential partners need to invest in these specific assets. In later work of Williamson (1993) these categories were supplemented with *brand name capital* and *temporal specificity,* two categories we do not incorporate into our model.

3.2.2 Frequency

The second critical attribute of a transaction is the frequency of occurrence. Williamson (1985) regards the frequency as an important attribute, from the point of view that the costs of specialized, expensive, governance structures will be easier to recover for large transactions of a recurring kind. In general, transactions with a high frequency will lead to learning effects, related to the formulation and negotiation of a contract. Here, the frequency refers to the frequency of the contractual purchases of products/services. In addition to this, Williamson (1985) argues that a high frequency will lead to reduced control system costs, i.e. reduced ex post costs per transaction and also a relative reduction of the *first buy* costs, i.e. ex ante costs (search for partners, negotiating etc.) since they will be covered by more transactions.

3.2.3 Uncertainty

A third key characteristic of a transaction is uncertainty, and the basic proposition in transaction costs analysis is that governance structures differ in their capacity to respond effectively to disturbances. As uncertainty rises regarding a buyer's future requirements, contracts become difficult to write, and producing a component in-house consequently becomes more attractive. In this case the transaction will be internalized, to economize on bounded rationality and provide safeguards against opportunistic behavior. There are several different origins of uncertainty that can be divided into two groups: the state-contingent type and behavioral uncertainty (which is linked to bounded rationality and opportunism). However, Williamson (1975) argues that the origin of the uncertainty is non-essential, what matters is that approximation must replace exactness in reaching a decision.

When there is a lack of communication, uncertainty will emerge, since one decision-maker has no way of finding out about concurrent decisions and plans made by others. This last arises due to non-disclosure, disguise, or distortion of information. Volume uncertainty has been shown to raise the transaction costs, but the costs incurred due to technological uncertainty may be greater in-house than if the production had been outsourced. The possibilities for the buyer to shift the technological risk to the suppliers is dependent on whether or not he has alternative suppliers to turn to or that the switching costs are low.

3.2.4 Transparency

Asset specificity, frequency, and uncertainty form the essence of the theory of TCA and will be incorporated in the network design model. However, there are additional contingencies that need be considered when modeling the decision to participate.

Transaction Costs Analysis operates on the assumption that managers are motivated solely by efficiency considerations; that is, they will select that least costly of these alternatives, taking into account the combined effects of transaction and production costs. The implications of trusting behavior in designing governance mechanisms are generally ignored, although Williamson (1985) observes that "*other things being equal, idiosyncratic exchange relations that feature personal trust will survive greater stress and will display greater adaptability*". Pfohl and Large (1992) argue that, when the asset specificity increases, there will be difficulties in finding a common market price, and therefore the price of the goods must be negotiated. This will lead to high transaction costs, and these will be increased further by the fact that the scope and the quality of what is purchased also has to be very precisely defined and is difficult to measure.

Another issue is the level of measurability; how well the effects, (benefits, costs, risks, etc.) can be measured and communicated between (potential) partners. Both terms are referred to in this dissertation as transparency. Pfohl and Large (1992) claim that transparency between partners will reduce the transaction cost by reducing the controls. Another aspect of what is referred to as transparency in this thesis is trust. Trust is defined as the confidence in the other's goodwill (Friedman 1991) and is enabled through recurrent transactions. The more frequently the parties have had successful transactions, the more likely they will bring higher levels of trust to subsequent transactions. The selection of the mode of governance depends on the risk of the transactions and the level of trust that is developed between the partners during the repeated transactions. Risk stems from uncertainty. Ring and Van de Ven

(1994) assume that the degree of risk inherent in any transaction generally will rise in direct proportion to decreases in time, information and control. The emergence of trust allows firms to engage in transactions without entering a process of negotiations and drafting of contracts. Trust reduces transaction costs and can increase the responsiveness of organizations to change in the business environment as contracts can be established more quickly.

In general, trust is more effective than legal contracts at minimizing transaction costs for a number of reasons. First, ex ante costs are lower for the buyer because the buyer does not need to compare different offers in order to be sure they are getting a fair deal. Assuming that the supplier is relatively efficient, the buyer can trust that the price and the quality offered by the supplier are fair. Second, negotiation and contracting costs (ex post costs) are reduced because the exchange partners are more likely to make the information transparent and trust that payoffs will be divided fairly. Consequently, exchange partners do not have to bear the cost, or time, of specifying every detail of the agreement in a contract. Further, contracts are less effective than trust at controlling opportunism because they fail to anticipate all forms of cheating that may occur. However, firms do not solely exist based on efficiency reasons only, but can also be the result of a complex of cultural and social factors. Interdependencies within ongoing channel relationships that serve to lessen tendencies for opportunistic behavior tend to be ignored.

3.3 Types of collaboration

Relationships between organizations can range from arm's length relationships to complete vertical integration of both organizations. Literature on relationships in logistics networks shows a variety of terms and perspectives: supply chain partnerships, supply chain collaboration, supplier-buyer relationships, purchasing and, supply management. Ellram *et al.* (1989) use industrial organization theory and transaction cost economics theory to position logistics network relationships. They compare vertical integration, obligational contracts and supply chain management. A supply chain management relationship is defined as an integrative approach to using information to manage inventory throughout the channel from source of supply to end-user. Ellram *et al.* (1990) position supply chain management as a hybrid form between transactions and hierarchies. They claim that "*within the supply chain, relations may take on a variety of legal forms, including equity ownership, joint ventures, short and long-term contracts and mutual understandings*". Lambert *et al.* (1997) distinguish three types of partnerships in logistics networks.

Type I consists of organizations involved that recognize each other as partners and, on a limited basis, coordinate activities and planning. The partnership usually has a short-term focus and involves only one division or functional area within each organization. *Type II* is a partnership in which the organizations involved progress beyond the coordination of activities to the integration of activities. Although not expected to last forever the partnership has a long-term horizon. Multiple divisions and functions within the firm are involved in the partnership. In *Type III* partnerships, the organizations share a significant level of operational integration. Each party views the other as an extension of their own firm. Typically no "end date" for the partnership exists. The way in which organizations manage their relationships has been changing over the past two decades. As late as the mid-1980s transactions between buyers and suppliers tended to rely on arm's length relationships based on market price, while relationships in the 1990s relied more on trust derived from collaboration and information sharing. Scott and Westbrook (1991) identify keeping the supplier at arm's length, changing suppliers frequently and rewarding contracts to the supplier with the lowest quote as the key attributes of a good supplier relationship. While in the market model, while market control ensures price competitiveness in the short term, it reduces the long-term competitiveness, curtailing investment in new products and capabilities.

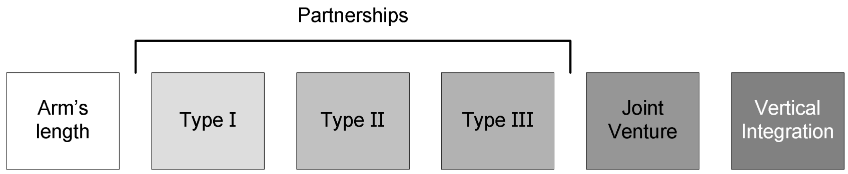

Figure 3-3: Types of relationships in the logistics network. Source: Lambert *et al.* (1997).

Supply chain management can also increase the dependency of the buyer or supplier on the other partner. The presence of trust and commitment between buyers and suppliers are the foundations for building a stable and long-term relationship. However, if the threat of opportunism is real, buyers and suppliers must consider the trade-offs between flexible, informal agreements, based on trust and inflexible agreements founded on a legal document. The *Joint Venture* type of relationship or partnership indicates primarily how the transaction and activities between the partners are governed. In Figure 3-3 the continuum of partnerships, presented by Lambert *et al.* (1997) that we use to classify collaboration is presented.

3.3.1 Scope of the collaboration

Next to the types of collaboration it is important to identify the scope of these forms of collaboration. Boorsma and Van Noord (1992) group different types of cooperative activities into four types of supply chain integration with differences in scope:

(1) *Physical integration*; refers to changes in processes and activities that aim to improve the efficiency of the primary process. As a result of improving the interface between two companies the logistics costs can be reduced.

(2) *Information integration* refers to the exchange of information related to inventory levels, manufacturing or transport planning, forecasts, actual status of processes etc. with supply chain partners. Transparency within the supply chain is improved as each company has a view on what is happening elsewhere in the supply chain.

(3) *Coordination integration* refers to the alignment of the decision-making processes along the supply chain. Information from other parts of the chain is systematically used to plan and control activities. The supply chain operates as if it was a single organization. The primary goals are to realize cost reductions by means of lower inventories along the supply chain and efficient use of resources, and to improve customer service levels.

(4) *Supply chain coordination* refers to cooperation in which the structure of the supply chain changes or tasks and responsibilities are shifted from one supply chain partner to another. This shift of tasks and responsibilities exceeds the more traditional outsourcing of logistics or manufacturing activities.

In section 2.2.2 we presented a similar hierarchy of decision-making in logistics depending on the scope, investments required, time horizon, and frequency of the decisions involved.
In classifying the scope of the collaboration we will use the same hierarchy, namely at the first level collaboration aimed at the structure of the logistics network; at the second level collaboration concerning the alignment of the network; for example inventory levels, locations and safety stock; at the third level decisions collaboration, aimed at the scheduling aspects of the logistics network (e.g. delivery frequency, shipment sizes, order lead times, stock replenishment); finally, at the fourth level, collaboration aimed at the resources and the efficient and effective deployment of these resources are taken (e.g. vehicle routing, load planning, order handling, and order picking). The type of integration, that is, the activities firms actually coordinate and perform together, is of primary importance in logistics.

3.3.2 Contractual exchanges

The type of contract which governs the collaboration speaks volumes about the relationship. The strongest partnerships generally have the shortest and least specific agreements or no written agreement at all. The type of contract is usually a measure of the trust and commitment between the partners. We distinguish between different types of contracts ranging from a simple short-term vendor contract, to a strategic long-term partner agreement. Three categories are distinguished: (1) contractual exchanges, (2) inter-organizational agreements, and (3) the trans-organizational agreement. The first category is characterized by short-term contracts. Usually a simple contractual exchange involving a future act or obligation (*executory bilateral contract*), a series of contracts linked serially and conditional on one another (*sequential contingent contract*), or a contract in which certain terms (e.g. order amount, price, terms of trade) are deliberately left open to be agreed on at a later date (*open-ended contract*). The second category is characterized by a medium term and these are usually inter-organizational exchanges involving traditional (e.g. purchasing, sales, vendors, etc.) boundary spanning linkages and coordination. This type of contract is used in a Type II collaboration.

Finally, we distinguish the long-term trans-organizational agreements. This type of agreement is usually an inter-company coalition composed of a system of partner roles and responsibilities organized inter-functionality (e.g. research and development, marketing, production, etc.) and supported by a network of coordination, liaison, and decision-making linkages. A second type of long-term agreements is a *Joint Venture* agreement and entails the creation of an autonomous entity, usually organized by function, with or without equity position by the partners in the entity. Examples of these types of agreements are non-equity arrangements involving research and development, production and marketing; equity sharing arrangements; satellite organizations. Gundlach and Murphy (1993). We categorized these types in Type I, Type II, and Type III in accordance to the three types of collaboration presented in Figure 3-3.

3.3.3 *Vertical* versus *Horizontal* collaboration

Collaboration is the act of several parties working jointly and several forms of collaboration exist covering almost all areas of people's life like for example at work, where people are employed by a company being involved in producing a good. Within this example, the employees have the same goal of producing a good. However, there exist collaborations where each party has its own goal that can only be achieved by interacting with other people, like for example, people going shopping at a market or companies having joint ventures. Primary among the issues involved in structuring a channel in the logistics network is determining the level of integration, as emphasized by Stern and El-Ansary (1992). A high level of integration exists when a firm focuses on internal administrative mechanisms (e.g. company sales force, warehousing, distribution, etc.) to bring products or services to their customers. A low level of integration reflects reliance independent of subcontractors or partners. When a company seeks collaboration it can either collaborate vertically or horizontally. Traditionally, the focus in logistics has been on vertical integration and collaboration. In Figure 3-4 an example of vertical collaboration is illustrated. The focal company, Firm I, is participating in a collaboration with customer (C). In this example a manufacturing company and a retailer, in the same channel, collaborate.

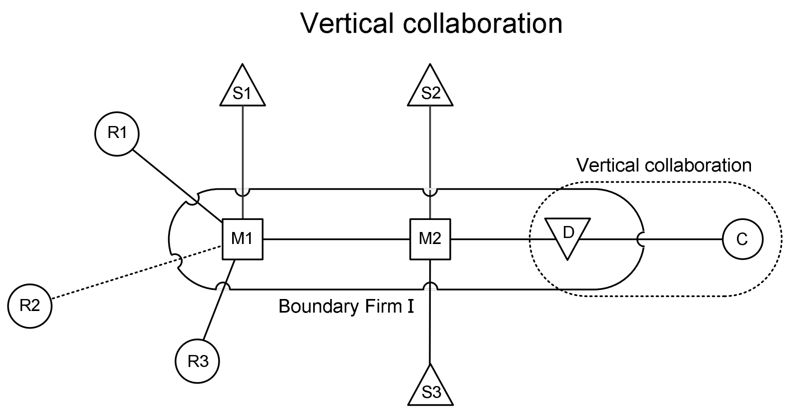

Figure 3-4: Schematic representation of vertical collaboration between focal company (Firm I) and Customer (C).

However, more and more attention is devoted to lateral or horizontal collaboration. In Figure 3-5 an example is depicted of a horizontal collaboration between two firms. The scope of this collaboration is the distribution function of both firms; they jointly execute their physical distribution. A recent example of such a horizontal collaboration, which will be discussed in detail in Chapter 6, is the collaboration between the manufacturers Douwe Egberts, Masterfoods, and Unipro, with in addition the logistics service provider C. van Heezik. The three manufacturers have a considerable overlap in customers and consolidated their physical distribution activities, outsourced to C. van Heezik.

The distinction between vertical and horizontal collaboration is only relevant for our design framework if the choice-behavior of the companies and actors involved is influenced. If, for example, company A is analyzing a horizontal collaboration, but its primary competitors are already participating, resistance of company A will probably increase and the likelihood of participating will therefore decrease. However, if the collaboration initiative is horizontal collaboration in which six other manufacturers participate from completely different sectors, the influence of being a horizontal initiative is probably minor.

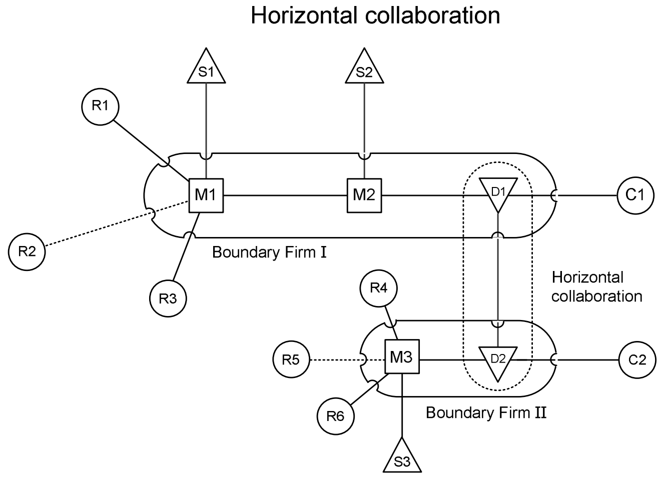

Figure 3-5: schematic representation of horizontal collaboration between Firm I and Firm II..

In the remainder of this dissertation we will denote horizontal collaboration by a subscript indicating the number of actors that are willing to collaborate. For example, in the figure above, a subscript placed at $D1_2$ would indicate that 2 actors collaborate. Note that vertical collaboration is usually depicted horizontally (as in Figure 3-4) and a horizontal collaboration usually with a vertical orientation.

3.4 Drivers and barriers of collaboration

The combination of several organizations can lead to synergetic effects that can be the incentive for new market development. By collaboration companies can achieve an increase in flexibility and can benefit from each other's networks. This can lead to a faster development process of new products or services. Next to this advantage in *flexibility* and *time to market,* asset and cost efficiencies are obvious drivers to collaborate. Lambert *et al*. (1996) distinguish four drivers for collaboration, and suggest that in order to achieve a successful collaboration both parties must believe they will receive significant benefits in one or more areas and that these benefits would not be possible without a partnership (transparency). In an environment characterized by scarce resources, increased competition, higher customer expectations, and faster rates of change, executives are turning to partnerships to strengthen supply-chain integration and provide sustainable competitive advantages. The selection of a supply-chain relationship can be approached from a strategic, operational and purchasing perspective and is based on a wide variety of contingencies. To assist organizations and supply-chain managers in the selection of the appropriate relationship several portfolio models or typologies have been presented (Kraljic 1983; Bensao 1999; Lambert *et al*. 1997). For a comprehensive overview we refer to Verduijn (2004). Next to the drivers we will discuss below, several important barriers are mentioned in the literature. For example, the increased dependency and high switching costs associated with finding suitable partners are often mentioned (Aerts 1998). In addition, due to the increased complexity and interaction with the partners, the operating costs during the beginning will increase and the investments will be high. Other barriers mentioned are the loss of control, the increase in risk and difficulty in measuring and sharing the costs and benefits. At the other end of the spectrum the drivers can be identified. These drives include:

(1) *Asset or Cost efficiencies;* a potential for cost reduction provides a strong reason to partner. Closer integration of activities may lead to reductions in transportation costs, handling costs, packaging costs, information costs, or product costs and may increase managerial efficiencies. McDonald's found that by establishing partnerships with regional distributors who serve as the single distributor for all products to all stores within a region, delivery and ordering cost were reduced.

(2) *Customer service;* integrating activities in the supply chain through partnerships can often lead to service improvements for customers in the form of reduced inventory, shorter cycle time, and more timely and accurate information.

(3) *Marketing advantage;* a third reason for entering into a partnership is to gain a marketing advantage. A stronger integration between two organizations can: (a) enhance an organization's marketing mix, (b) provide entry into new markets, and (c) give better access to technology and innovation.

(4) *Profit Stability or growth;* a potential for profit improvement is a strong driver for most partnerships Strengthening a relationship often leads to long-term commitments, reduced variability in sales, joint use of assets, and other improvements which enhance profitability.

In a recent survey, conducted amongst 154 shippers, carriers and logistics service providers (Dullaert *et al*. 2004), the drivers above were rated as the most important for participating in partnerships and collaborations. In the remainder of this dissertation the above four drivers will be used to denote the objective of the collaboration.

3.5 Dominance

One of the important issues in business logistics is the concept of power, or asymmetry, as referred to in the relationship between firms. In our approach, dominance reflects its potential for influencing the actions and decisions of individuals and firms in the network. This is in contrast to the focus in behavioral channels research on power at the dyadic level (Gaski 1984). Based on the resource-dependence perspective a number of strategic management researchers (Harrigan 1983; Porter 1980) indicate that a firm's power at the system level will have a major impact on the structure of the channel, and on the logistics network as a whole.

Specifically, they argue that a firm with high-level dominance is more likely to make use of non-integrated strategies, given the leverage it will possess over associate entities. In addition, Grossman and Hall (1986) argue that the benefits of vertical integration are not attributable to ownership per se, but on the ability to exercise decision control. While Heide and John (1988) focus on how relational norms impact the firm's ability to structure exchange relationships in desired ways, they also argue, from a dependence theory perspective, that a firm's dominance may serve the same purpose. Historically, advocates of TCA have been reluctant to acknowledge the possible contributions of this dominance constraint.

Describing logistics networks in terms of properties of products and services provided can only take one so far. To be able to understand whether participation at any point in the logistics network or a collaborative network is desirable or practical requires that the actors (retailers, manufacturers, service providers, etc.) understand whether the ownership and control of particular network resources will generate a sufficient financial return to make participation worthwhile. The creation of products and services is not primarily to provide value to customers, but to make money for those who are involved in the logistics network. It follows that if one is to properly understand logistics networks, and what can and cannot be achieved with them, it is necessary to move from a description of the physical properties of products and services in these networks to a more analytical understanding of the relationship between actors and the flow of value that occurs in the network.

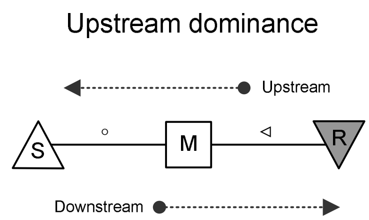

Figure 3-6: Example of a two tier buyer-supplier relationship with downstream dominance of the retailer (R).

Value is used in three broad ways. Firstly, it is used to refer to the utility that the customer derives from the product or service acquired. This is normally referred to as the customer's *value proposition.* Secondly, it is used to refer to the transformation process that takes place within the organizations as they take less valuable supply inputs and turn them into more valuable supply outputs. This is normally referred to as the *value-adding process.* The third way in which value is used in relation to the amount of money retained by any organization from participating at a particular stage in the logistics network is referred to as *value appropriation.* Each of these uses of value implies some sort of relationship between what is physically done and its utility (the financial and non-financial benefits that are derived from doing it). A customer pays price x and obtains utility y from the possession or use of a product or service. An organization physically transforms supply inputs at cost a, and is able to sell a value-added product or service at price b, generating a particular level of revenue. The same organization assesses the relationship between what it does physically, the cost of capital to do so, and the revenue received, and then ascertains whether the costs of doing so allow it to appropriate sufficient value to justify doing what is currently being done at that point in the logistics network. Each of these ways of thinking about value is appropriate in business thinking. The first way - focusing on *value propositions* - enables organizations to think about the wants and the needs of customers, as well as what must be done (and at what price) to win a larger share of the available market. The second way - focusing on value-adding processes - helps an organization to think about the unique activities that allow the organization to make distinct and unique products and service. The third way - focusing on *value appropriation* - allows the organization to think about whether what it does provides it with an acceptable return on its capital employed (Cox *et al*. 2001).

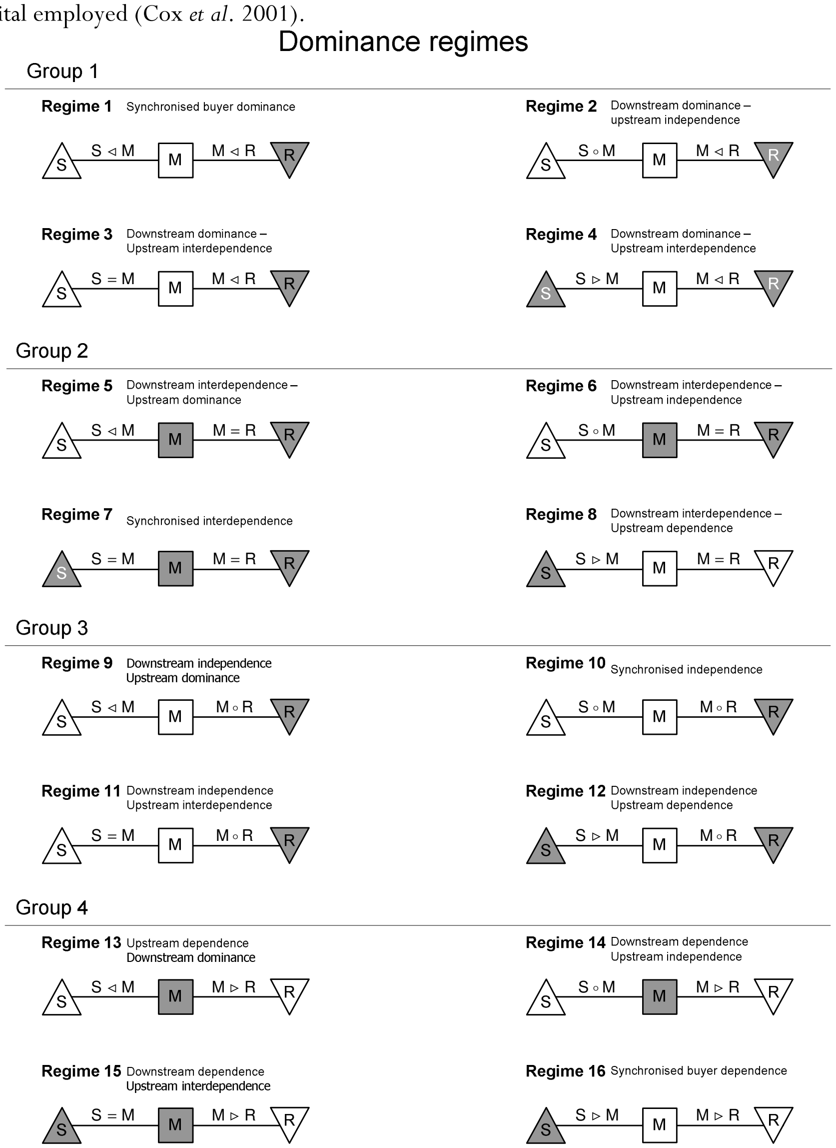

Figure 3-7: Value appropriation in different exchange scenarios or dominance regimes. Source: Cox *et al.* (2000).

Next to the management of their value appropriation opportunities within a complex logistics network they have to manage internally a myriad of upstream and downstream buyer and supplier relationships. Interestingly enough, the complexity that organizations have to deal with when they act as buyers is not simply explicable in terms of the number of supply relationships they must manage. On the contrary, first-tier supply relationships must also be understood in terms of the extended network of power relationships that the buyer and its first-tier supplier must manage. On the contrary, first tier supply relationships must also be understood in terms of the extended network of power relationships that the buyer and its first-tier supplier must manage. These extended networks of dyadic power relationships are called *power regimes*.

Figure 3-6 provides an example of a two tier buyer-supplier relationship of a supplier (denoted S), a manufacturer (M), and a retailer (R). We use the symbol ($S \triangleleft M$) or ($M \triangleleft R$), to denote dominance D of manufacturer (M) over supplier (S), or dominance of retailer (R) over manufacturer (M), respectively. *Supplier dominance* is indicated by the symbol ($S \triangleright M$) or ($M \triangleright R$); buyer-supplier interdependence by ($S = M$) or ($M = R$); and *buyer-supplier independence* by ($S \circ M$) or ($M \circ R$).

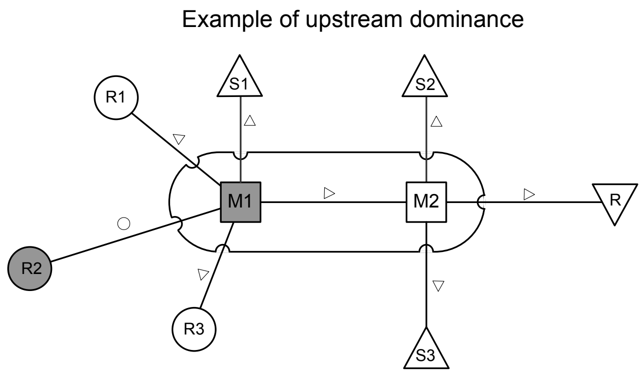

Figure 3-8: Example of value appropriation in complex power regime with upstream dominance.

Figure 3-7 provides an analytical typology of 16 hypothetical buyer-supplier double dyadic exchange scenarios. Group 1 contains those regimes where retailer (R) has power over manufacturer (M), with ($M \triangleleft R$). Group 2 contains those regimes where (R) and (M) are interdependent ($M = R$). Group 3 contains those regimes where (R) and (M) are independent of one another ($M \circ R$). Finally, Group 4 contains those regimes where (M) has power over (R), ($M \triangleright R$). Each of these four groups has been further categorized on the basis of the power relation that exists between manufacturer (M) and supplier (S). Each one of the four possible power relations between (M) and (S) is represented in each group. This is because the manufacturer (M) stands between source (S) and its final destination (R).

In Figure 3-8 a hypothetical power regime is constructed and is based on the linkage of dyadic exchange relationships consisting of nine actors (R1-R3, S1-S3, M1, M2 and R), where these actors have been joined together by means of eight exchange dyads to create a complex network of power relationships linked together to create goods and/or services for end users. In effect, this could be seen as a logistics network consisting of a retailer (R), two manufacturers (M1 and M2), three suppliers (S1, S2 and S3) and three suppliers of raw materials (R1-R3). In this example it is evident that the upstream actors dominate the actions of retailer (R). When for example a collaboration between M1-M2 and R is evaluated this dominance of M1-M2 over R could be a reason for retailer R not wanting to participate or adding safeguards resulting in additional transaction costs when joining. This resistance to participate is very difficult to measure, but undoubtedly plays an important role in the assessment of any collaboration initiative.

Structural Embeddedness

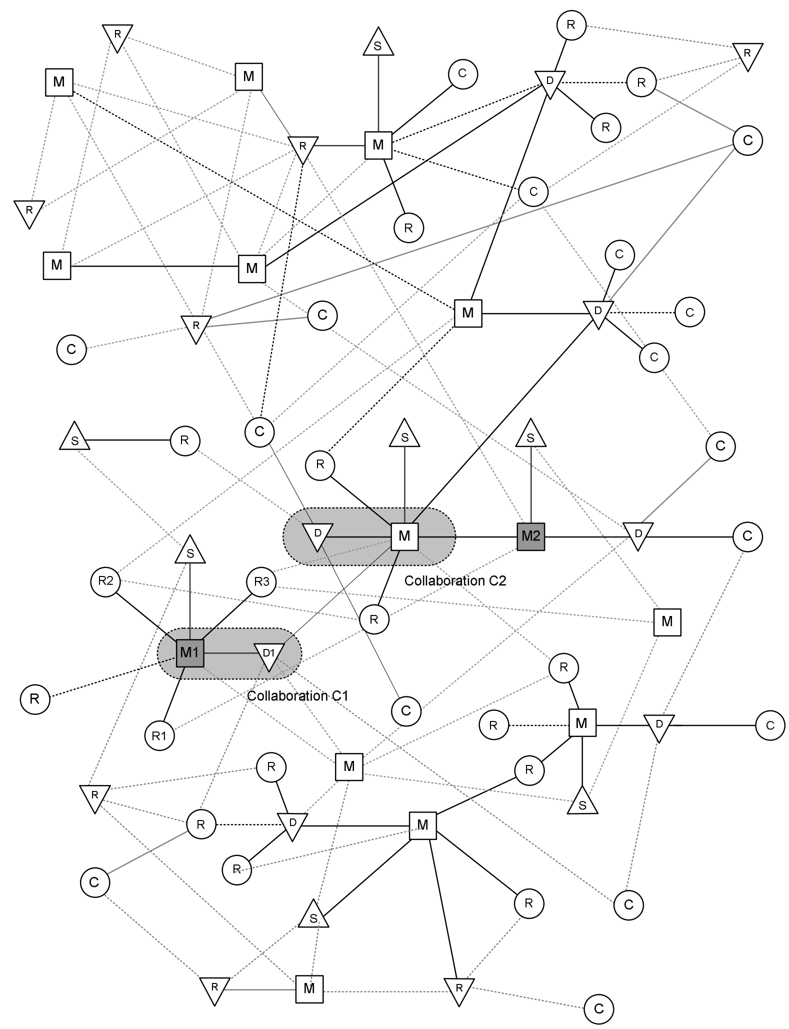

Figure 3-9: Structural embeddedness and dominance in the logistics network.

Figure 3-9 depicts a logistics network with a complex of relations and interactions. Although this is still a simplification of a real-life network, it illustrates the myriad of relations and interactions that need to be analyzed when optimizing the logistics network. In addition, when optimizing the logistics network of a focal company it is necessary to analyze its relations and interactions with other actors in the network, but also its position in the network and the dominance of other actors, both up and downstream. This is referred to as structural embeddedness and indicates the fact that economic actions and outcomes are affected by the actor's dyadic (pair-wise) relations, and by the structure of the overall network relations.

Looking at the position of specific actors in the network provides insight into the structural embeddedness. What is the influence of the actions or participation of, for example, manufacturer M1 on the actions of R1, R2, and R3? In the figure presented above, two examples of collaboration are depicted (collaboration C1 and collaboration C2). The first example, collaboration C1, indicates a partnership between D1 and M1. Should R3 participate, given the transaction costs and the dominant position of M1, and given the ability of M1 to appropriate value? Additional resistance of R3 to join the consortium of collaboration C1 is likely to be present. In the second example M and D participate without any specific dependency between them; both participants are independent and equally powerful. But what would be the reaction of the participants of collaboration C2 if M2 entered the consortium, due to its dominant position?

The concept of embeddedness is attaining attention of many researchers, economists and social scientists in particular. Among them, economists have been eager to embrace the notion of embeddedness, because it assumes that firms are closely linked to their local production environments in a world of increasing globalization. Embeddedness not only accounts for the importance of trust-based networks for regional development, but also incorporates the idea that socio-cultural and institutional factors may be essential for a good economic performance of firms. Therefore, trying to explain the reasons why under the same market conditions some of the actors are able to act in the market and others are not, the concept of embeddedness becomes one of the main notions that are able to clarify those non-market factors. Most studies have been focused on the societal benefits that arise from the process of embeddedness.

Starting with Polanyi (1944), Granovetter (1985), then Uzzi (1996), Boschma (1999), Hess (2004) try to elaborate this confusingly polyvalent concept, but still there is now a plethora of meanings and definitions of what embeddedness might be or consist of. Some of them emphasize distinction between political, cultural, structural and cognitive mechanisms. Others make a distinction between micro and macro embeddedness, focus on temporal embeddedness, technological embeddedness, or recognize embeddedness as having four basic forms – cognitive, cultural, political, and structural.

Grabber (1993) stated that structural embeddedness has been recognized as having four essential characteristics: (1) *reciprocity*, (2) *interdependence*, (3) *loose couplings*, and (4) *asymmetric power* relations. *Reciprocity* refers to recurrent transactions between networked firms that are more than simply repetitive and involve relationships that do not have immediate equivalence in each transaction but achieve some approximate balance over the life of an exchange relationship Polanyi (1944). *Interdependence* reflects the elements of trust and mutual orientation in long-term exchange relationships that enable firms to exchange resources and information crucial for high performance but difficult to value and transfer via market ties (Uzzi, 1996). It is central to network learning and local innovation capacities. *Loose coupling*, or integrated separateness, recognizes the ability of firms networked in a place individually to shift their partners while maintaining an essentially stable district framework of interaction. *Asymmetric power relations* are a counterweight to the coziness of network collaboration, with collaboration and cooperation within networks being undermined by practices of dominance and exploitation between unequal exchange partners Dicken *et al*. (1992), Grabber (1993), Taylor (2000). Trust-based supplier relationships reduce the risk of opportunistic behavior by exchange-partners and reduce transaction costs on the specification and monitoring of contracts. When trust is high, there is less need to specify all the details of a transaction in formal written contracts. Norms that are shared effectively constrain opportunistic behavior, so the need to control and monitor transactions is also reduced. As Harrison (1992) states, firms are said to co-operate on getting new work into the district, in forming consortia to obtain cheap credit, in jointly purchasing raw materials, in bidding on large projects and in conducting joint research. Embedded relationships greatly enhance flexibility, because the partners retain some autonomy, and autonomy prevents lock-in. In strongly embedded networks, independent and autonomous firms both fiercely compete and closely cooperate. With good communications, independent partners may be able to shift goals and strategies more easily.

3.6 Discussion

While the presence of strong drivers is necessary for successful partnerships, the drivers themselves do not ensure success. The benefits derived from the drivers must be sustainable over the long term. If, for instance, the marketing advantage or cost efficiencies resulting from the relationship can be easily matched by a competitor, the probability of long-term partnership success is reduced. Drivers provide the motivation to partner. But even with a strong desire for building a partnership, the probability of success is reduced if both corporate environments are not supportive of a close relationship. On the other hand, a supportive environment which enhances integration of the two parties will improve the success of partnership.

The choice between in-house organization and collaboration is a fundamental decision in the logistics network. Firms are naturally reluctant to transfer responsibility for an operational area as vital as logistics to a third party. Fears about the loss of control, problems in maintaining customers' goodwill and the inability to replace or supplement at short notice a system that fails to perform are reasons given by logistical managers for not seeking collaboration and contracting out. Therefore an answer to our research question: "*under what circumstances will organizations decide to collaborate with third parties?*" is crucial, in order to be able to design a logistics network in which the different actors collaborate. This decision is based on several key aspects of the collaboration that is considered. In modeling this decision-making process we distinguish the following characteristics:

(1) *Scope and Objective of the collaboration;* based on the hierarchy in decision-making the scope of the collaboration is the structure of the network, the alignment, the scheduling or the resource deployment. The objective of the collaboration is either *asset or cost efficiencies*; customer service, marketing advantage, or *profit stability or growth*.

(2) *Type of collaboration*, we distinguish three types of collaboration; *Type I, operational collaboration*, usually focused on cost and asset efficiency; *Type II, coordination collaboration*; and *Type III, network collaboration*.

(3) *Asset specificity*, in any collaboration the asset specificity for the participants is a key determinant. It is therefore necessary, when modeling the choice-behavior, to gain insight into the asset specificity of all the actors.

(4) *Uncertainty,* a second important determinant is uncertainty and a key determinant of the height of the transaction costs (and hereby influencing the choice-behavior substantially).

(5) *Frequency*, the third contingency in *Transaction Costs Analysis* is the frequency of occurrence. This is considered an important attribute, from the point of view that the costs of specialized, expensive, governance structures will be easier to recover for large transactions of a recurring kind.

(6) *Dominance,* reflects its potential for influencing the actions and decisions of individuals and firms in the network.

(7) *Transparency,* refers to the trust between the participating actors and the measurability of the costs, benefits, performance, etc..

We will use these seven characteristics to categorize the different collaborations and by doing so it will be possible to gain insight into the influence of the collaboration on the transaction costs, logistics costs and eventually the logistics network design. These seven characteristics are of course a selection of the aspects that are involved in collaboration and network design. Issues of reciprocity, interdependence, and symmetry are of great importance, especially during the negotiation and implementation stages of collaborative networks. In the following chapters we will first address the different modeling approaches we will incorporate in our framework (Chapter 4), the network trade-offs (Chapter 5) and finally the formal model description (Chapter 6 and Chapter 7).

4 Modeling decisions in logistics

The logistics processes of most businesses today are highly complex, making it very difficult to process and use the plethora of data that arises from order processing, inventory management, production, shipments planning, freight payment and related systems. In these systems, items are produced at one or more factories, shipped to warehouses for intermediate storage and then shipped to retailers or customers. Consequently, to reduce costs and improve service levels, logistics strategies must take into account the interactions of the various levels in the logistics network. If we think about managing this decision-making process, the role of models becomes apparent.

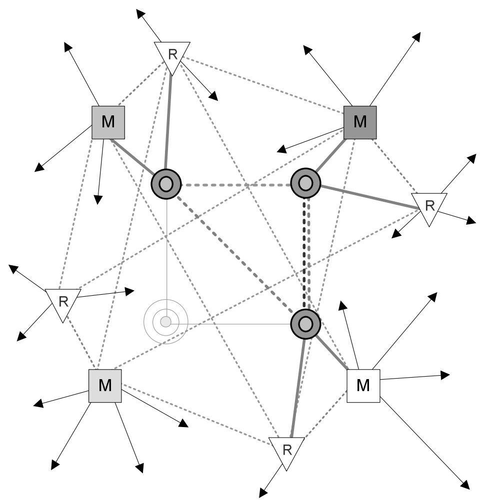

Figure 4-1: Schematic representation of the network design problem.

Basically decision-making is simply choosing between the available alternatives to obtain the best possible outcome. The more alternatives that can be generated, and the more completely we can evaluate potential outcomes, the better the chances for the decision-maker to make the right choice. Decisions related to the structure of a logistics network are among the most critical in business logistics. Consequently, a great deal of effort has been devoted to the development of mathematical models to support decisions related to the design of these networks. A comprehensive review of these approaches is beyond the scope of this work as the number of published papers is vast and available books are numerous (Shapiro 2001; Current *et al*. 2002; Hale 2003; De Kok and Graves 2004). In Figure 4-1 provides a schematic representation of our logistics network design problem. The three hubs are denoted by the gray circle symbol, and the inter-hub transfer is executed by different types of services, denoted by the dotted lines (blue, dark blue and green). The collection and distribution is either taken care of by a round-trip or direct origin-node to hub-node collection, or hub-node to destination-node distribution transportation. The products are either shipped through the hub-network or directly via origin to destination shipment.

The structure of this service network is derived using facility location models; the inventory locations and positions at the hubs are calculated with multi-echelon, multi-product inventory models; given the locations of the hubs the service network can be derived using service network design models, and finally, the routing problem can be calculated using vehicle routing models. Once a network solution is derived, an evaluative model can be used to simulate the network in more detail and assess the performance, in terms of costs and performance, of the network.

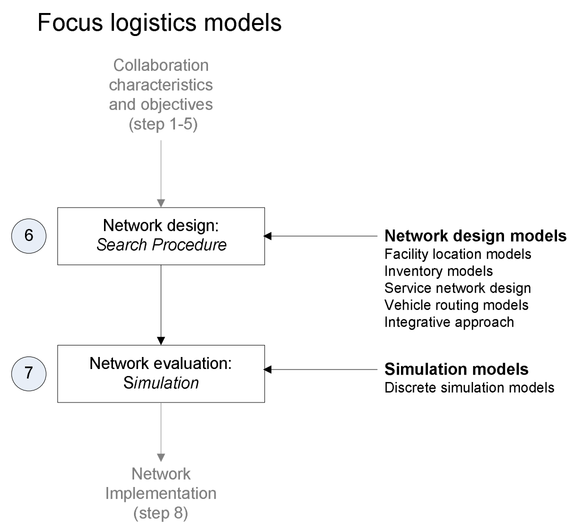

Figure 4-2: focus on the different types of models per step; Network design and network evaluation, step 6 and step 7 of the overall framework.

In Figure 4-2 two of the steps of our modeling framework are depicted, the network design phase and the evaluation phase[6]. Based on our objective we focus on these models we will be using and make extensions to, especially, facility location models, inventory models, service network design, vehicle routing, and integrative approaches (network design); and on discrete simulation models (network evaluation), which reflect the main components of the network design and evaluation phases of our framework. In the remainder of this chapter we will discuss the different simulation techniques available for evaluating logistics networks. This chapter is concluded with a discussion on the added value that can be achieved by combining normative and descriptive models and the innovations we propose in our network design framework.

[6] The overall modelling framework, including the two phases discussed in this chapter is presented and discussed in Chapter 6.

4.1 Taxonomy of models

Given the development of appropriate perspectives and understanding of requirements that different logistics strategies place on the logistics network, and an acquaintance with the basic system design concepts, a variety of analytical, mathematical and heuristic techniques can be helpful in the network design process. Logistics network design has offered a popular forum for the development and application of all types of models: static, dynamic, analytical, physical stochastic or deterministic. In addition to the numerous models there are numerous ways of classifying these models. Rather than catalogue all the different techniques and explain them in full, we will use taxonomy applicable to the models addressed in this dissertation. Figure 4-3 presents the taxonomy of models, consisting of six steps.

In classifying the modeling approach we first distinguish the four levels of decision-making: structure, alignment, scheduling, and resources. In the second step we make a distinction between spatial, temporal, and integrative applications. Spatial models deal with questions of location in, and movement through, space. Examples of these questions are facility location, specification of flows of goods between and through those facilities, allocation of orders for shipment to warehouses and plants, and selection of transport modes. They require as inputs data concerning transportation, production, and warehousing costs as well as spatial coordinates and distance estimates for alternative locations and transportation methods. Temporal Models in logistics typically deal with questions of storage over time, in other words inventory and policy questions. Simple inventory models under conditions of uncertainty, trade-off the costs of ordering, holding and stocking out and produce optimum solutions given a very limited set of assumptions. More complex models, often allowing the entry of multi-period order streams for product lines comprising many items, generally involve simulation techniques.

The third categorization element is the function of the model: design or evaluation. This distinction between design and evaluation is particularly important since these types of models are suited for fundamentally different purposes. Design models are used to generate solutions, and try to optimize the solution. This type of model is also often referred to as a normative model. A design model often makes use of evaluative techniques (like simulation). At its most simple, an optimization model is an evaluative model with added features: (1) the ability to generate new alternatives automatically, and (2) the ability to test whether a given alternative is the best. The first step in constructing an optimization model is the same as that necessary in constructing an evaluative model - the description of the system: specification of the set of equations (or inequalities) that characterizes the interrelationship of key system variables.

As their name implies, *evaluative models* operate by evaluating alternatives one at a time; they neither generate alternatives nor choose the *best*. The generation and selection of alternatives is done by the problem-solver or decision-maker. They permit a great deal of flexibility, and with a good understanding of the underlying system a relatively high level of representational accuracy can be achieved. On the other hand, there is a practical limit to the number of alternatives that can be evaluated. Typically, evaluative models are used in a *satisfying* mode, that is, the analyst or manager will evaluate candidate plans until he or she is satisfied with the performance of one or more. With an evaluative model, there can be no guarantee that the chosen alternative - the best alternative that has been evaluated - is the best alternative. During the fourth step some essential choices need to be made concerning the description of the process that is being modeled. Does the process description need to be static or dynamic, deterministic or stochastic, is the user population homogenous or non-homogenous, is there equilibrium or non-equilibrium within that population, and finally, is it discrete or continuous. When making these fundamental choices, based on the nature of the design question, the level of appropriate detail needs to be decided on.

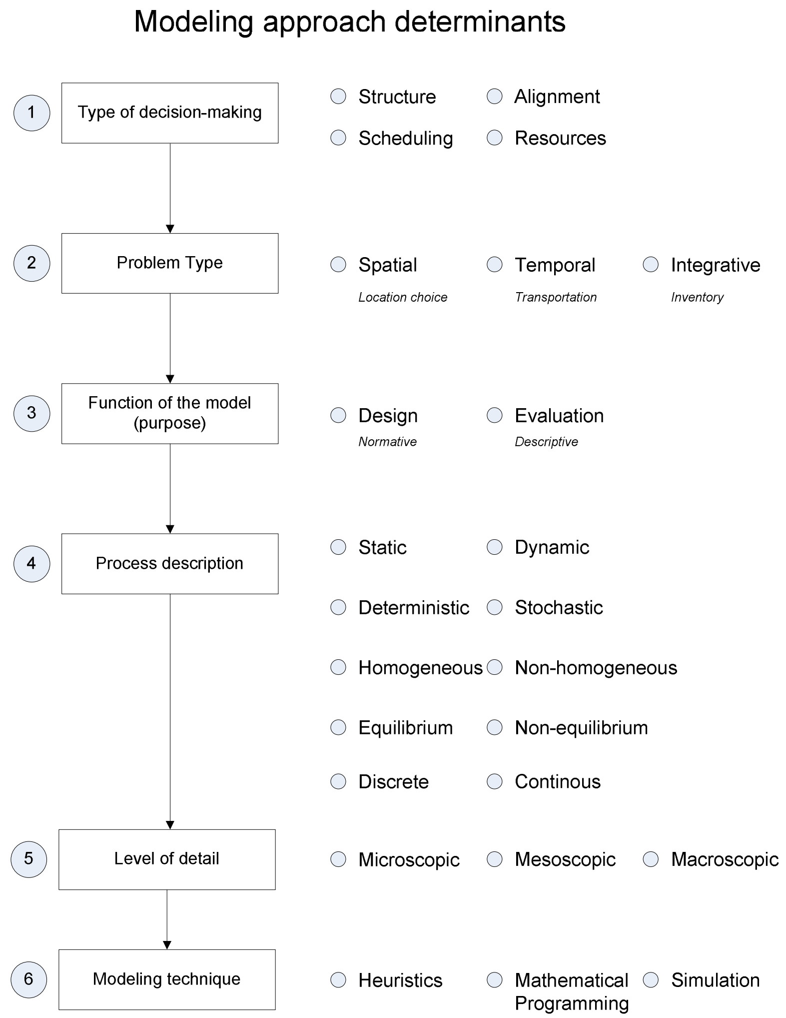

Figure 4-3: Modeling taxonomy

Then finally, the appropriate modeling technique needs to be selected. Note that the three techniques mentioned in Figure 4-3 are merely illustrative. Optimization models often require that the question being asked and the number of variables considered in addressing it be simplified to the point where the output must be significantly enriched by management judgment. Particularly successful applications of optimization models have been the use of mathematical programming in allocating inventories and shipments to one or more warehouses in a network and in aiding the location of production facilities or warehouses themselves. In contrast, evaluative models, such as simulation, may give a closer replication of real life, with the opportunity to consider more complex interactions between variables. The purpose of a simulation model is to mimic the real system so that its behavior can be anticipated or changed and to assess the different control strategies and algorithms. A simulation model is a laboratory replica of the real system. By creating a representation of the system, experiments can be performed which are either impossible or too expensive in the real world. There are many different simulation techniques, including stochastic modeling, input-output models, system dynamics, discrete simulation, and role-playing games.

A number of models used today, as well as several newly developed, highly successful models, fall into neither the evaluative nor the optimization camp. Instead, they rely on heuristics, rules of thumb, for choosing (not necessarily the best) plans from among a much larger set of candidate plans than would be possible with simulation or other evaluative approaches. Heuristics are especially useful in reducing the complexity for problems whose structure or size would otherwise make them computationally unmanageable. Many heuristics operate by decomposing a large or complex problem into sub-problems that can be more easily optimized. This is especially true of models for logistics network design, because sub-problems that seek to optimize flows between facilities can often be solved by efficient network procedures.

4.2 Modeling choice behavior

An important aspect in the taxonomy and network design framework we will present later on in this dissertation is the modeling choice-behavior of the actors in the logistics network. In this section we will briefly discuss some elementary constructs. Discrete choice models have a long history of application in, among others, economics, transportation, marketing, and geography. In general discrete choice models postulate that the probability of individuals choosing a given option is a function of their socioeconomic characteristics and the relative attractiveness of the option. To represent the attractiveness of the alternatives the concept of utility is used, which is a convenient theoretical construct, tautologically defined as what the individual seeks to maximize.

Two elements of the paradigm of choice are central to the development of a basic choice model. These elements are: (1) the function which relates the probability of an outcome to the utility associated with each alternative; and (2), the function which relates the utility of each alternative to a set of attributes that, together with suitable weights, determine the level of utility of each alternative. "*In conventional consumer analysis with a continuum of alternatives, one can often plausibly assume that all individuals in a population have a common behavior rule, except for purely random 'optimization' errors, and that systematic variations in aggregate choice reflect common variations in individual choice at the intensive margin. By contrast, systematic variations in aggregate choice among lumpy alternatives must reflect shifts in individual choice at the extensive margin, resulting from a distribution of decision rules in the population*" (McFadden 1974). Many economic decisions are complex and involve choices that are non-marginal. Typical examples include the choice of occupation, choice of ownership of particular consumer durables, choice of house type and residential location, choice of mode of transport and choice to participate in a collaboration.

Economists, however, are primarily interested in market demand, which is the result of the sum of individual demands over the population according to a rule of aggregation. Given that each individual is making individual consumption decisions based on their individual needs and the environment, the complexity of these individual decisions makes the relationship between the market and the individual demand even more complex.

The most common theoretical base, framework or paradigm for generating discrete choice models is the random utility theory (Domencich and McFadden 1975), which basically postulates that individuals belong to a given homogenous population Q, act rationally and possess perfect information, i.e. they always select that option which maximizes their net personal utility (the species has even been identified as '*Homo economicus*') subject to legal, physical and/or budgetary (both in time and money terms) constraints.

As discussed in Chapters 6 and 7, we assume that the actors in the network follow deterministic choice-behavior. It is, however, important to realize that adding the random utility theory in at a later stage would be an extension.

4.3 Network design models

An optimization model typically consists of three parts: (1) the objective function specifies the goal or objective. For example, for a salesperson, the objective is to minimize the travel time or total mileage on a trip; (2) the decision variables represent the choice to be made. In the case of the salesperson this could be the order of cities to be visited; and (3) the constraints restrict the choices of the decision variables to those that are possible or acceptable. The constraints in the salesperson's problem would specify that each city must be visited at least once, and would restrict the selection of routes to the available connections. Thus, a design model takes as input the goals to be met, the choice to be made, and the constraints to be satisfied. It yields as output the best decision that can be made given the assumptions of the model.

Our primary objective is to develop and demonstrate a design and evaluation methodology for logistics and transportation networks in which the participants collaborate, in particular, in a collaborative hub-network. Generally speaking, the objectives we focus on in our network design methodology are cost minimization and service maximization. In order to reach this objective we need to incorporate the following primary decision variables: the number and location of the hubs, the services between these hubs, the capacity of the hubs and services, inventory positions, and the routing of the shipments. This corresponds with the different types of models presented in Figure 4-2. The decision (variable) to participate, a key extension of the existing network design models, was discussed in Chapter 3.

In the remainder of this section we focus on specific design models that cover the four stages of decision-making in logistics mentioned in Chapter 2. A review is presented of the models that deal with the structure of the logistics network; the facility location models; the alignment of the network (inventory models). Next, models that deal with the scheduling of the product flow will be briefly discussed (service network design models). Then models that aim to optimize the management of logistics resources, e.g. transport and routing models, will be discussed. Finally, we will discuss the *state of the art* of integrative approaches to logistics network design where a combination of the different models presented (facility location, inventory models, service network design, vehicle routing) is sought.

4.3.1 Facility location models

The analysis of facility location problems has represented an attractive field of research since the beginning of the century. The very first location model, attributed to Alfred Weber, appeared in 1909 (Weber 1909) and dominated the literature for many years. However, a unified field of study called facility location did not emerge until the 1960s. The seminal paper by Hakimi (1964), published in 1964, established important results in location theory and sparked new theoretical interest among researchers (Hakimi 1964)[7].

An example of location problems, in their most general form, could be described as follows. A set of customers spatially distributed in a geographical area originates demands for some kind of services. Customer demand must be supplied by one or more facilities, which can operate in a cooperative or competitive framework, depending on the type of good or service being required. The decision process must establish where to locate the facilities in the territorial space, taking into account user requirements and possible geographical restrictions (Scapparra and Scutellà 2001).

Each particular choice of facility site implies some set-up cost for establishing the facility, and some operational costs for serving the customers. Issues like cost reduction, demand capture, equitable service supply, fast response time and so on, drive the selection of the facility placement. The generalized statement of the problem we provide above emphasizes the presence of three main elements which play an essential role in all location problems, namely facilities, customers and locations. The characterizing features of these elements and the different combinations of them within a model are sufficient to define the structure underlying a wide range of applications and allow the characterization of a representative sample of problems.

The second essential element for setting the stage for arbitrary location models is the physical place where the facilities can be positioned, i.e. the set of locations. With respect to the set of eligible points, three spatial representations are possible, namely continuous, discrete, and network. In the discrete case, the decision-maker can specify a list of plausible sites for facility locations. This kind of solution space proves to be very flexible because it makes it possible to incorporate a number of geographical and economic features into the model. On the other hand, many location applications are based on the assumption that the underlying space both for facilities sites and pre-existing points is a continuous one, where all points are determined by one or more coordinates which may vary continuously.

For many applications the graph-theoretic approach lends itself in an excellent way to an intuitive representation of the problem. However, for our approach, where we will be making use of a detailed network description to derive the shipment times and costs, we will use the network-based approach and predefine the number of potential facility locations (or potential hub locations). To illustrate the methodology of facility location we will discuss a relatively simple facility location model with the objective of minimizing the total distance traveled. The decision variables are the location of p hubs (number of hubs is predefined) and the customer assignment.

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[7] For some key references on location theory, classification schemes, reviews and applications see Carrizosa *et al*. (1995); Eiselt and Laporte 1993; Labbè and Louveaux 1997; Hamacher *et al*. 1998; Hesse Owen and Daskin 1998; Scapparra and Scutellà 2001, Drezner and Hamacher 2002; Hale 2004.

Median location problems.

The *p-median* problem, first formulated by Hakimi (1964), locates *p* facilities and assigns demands to the facilities to minimize the total distance between demands and the facilities to which they are assigned. In the absence of capacity constraints or other complications, each demand will be assigned to the nearest facility. Hakimi (1964) showed that at least one optimal solution consists of locating only on the nodes of the network. The *p-median* problem, in its most general and simplest form, is characterized by the following facility, location and customer features and relations. Facilities to be located do not have capacity restrictions, their number is fixed to *p* and they all provide the same kind of service. Locations have a network-based spatial representation with customers positioned at the nodes and facilities anywhere on the links and the vertices. Customers require a fixed amount of service for a single commodity and they always choose to be served by the closest facility among the ones being established. Their relation to locations is expressed through a distance function, which represents the shortest path on the network to reach the location. The objective function minimizes the demand-weighted total distance traveled. The constraints ensure that *p* facilities are located, the total demand assigned to the facilities, does not exceed demand. This formulation assumes that the potential facility sites are nodes on the network. A variety of extensions and variations on this classical model of the p-median problem are available (Drezner and Hamacher 2002).

A second class of location problems that is well studied includes the so-called covering problems. The idea of covering models is to identify locations that provide potential customers access to service facilities within a specified distance or travel time, the objective being to *cover* customers in order to *capture* their demand. The relation between customers and facility locations, which provides the performance measure, represents the basis for the definition of *coverage* and is usually expressed through the notion of distance (Scapparra and Scutellà 2001). A second group of covering models has also been studied where coverage is optimized with a limited budget. The budget restriction is reflected as a constraint on the number of facilities to be sited, which is known a priori. A customer demand is deterministic and fixed and becomes the objective of the problem to be maximized. The resulting model is the *Maximal Covering Location Model* (Church and ReVelle 1974; White and Chase 1974). Covering models have also been extensively studied to deal with the customer-facility relation concerning facility availability when customers require the service.

A third class of very well studied problems in location analysis, which are relatively simple to characterize, is the class of *p-center problems*. Rather than taking an input coverage distance W, this model determines endogenously the minimal coverage distance associated with locating *p* facilities. Under many aspects, *p*-center problems are almost identical to *p*-median problems. The major feature differentiating the two classes concerns the overall customer-location relation. The problem consists of finding the locations of *p* facilities that cover all demand nodes in the minimal possible distance, which is determined endogenously and is the objective function of the problem. The *p*-center problem is also known as the *minimax* problem, as we seek to minimize the maximum distance between any demand and its nearest facility.

Finally, a class of location problems, mentioned here, is represented by warehouse location problems, whose name derives from the fact that they aim to determine the best sites for intermediate stocking points while planning physical distribution systems. There are two main aspects in which this model class differs from the *p*-median class, related to the facility-location and to the facility features. The first refers to the presence of fixed costs for operating and locating facilities which relates supply centers to the specific location where they are sited; the second concerns the number of facilities to be opened which is not known a priori. Additionally, the efficiency criteria used to drive the site selection is the minimization of the total cost, i.e. the sum of the set-up cost and the transportation costs. Such an objective is usually referred to as a *fixed-charge* objective. The simplest in this class is the single commodity case involving unlimited capacity, single-echelon and linear costs. Warehouse location problems began to appear in the operations research literature with such papers as Baumol and Wolfe (1958). Since then, they have been extensively studied by many other authors who have proposed different variations of the original model and several solution methodologies.

Formulating an appropriate model is only one step in analyzing a location problem. Another challenge is identifying the optimal solution (Current *et al*. 2002), as even the most basic models are classified NP-hard. Due to this complexity other methods to identify optimal solutions, or at least very good ones, must be devised. Thus several researchers have begun to develop sophisticated mathematical programming *heuristics* for facility location and hub network design. Different techniques and heuristics have been developed.

4.3.2 Inventory models

Once the structure of the logistics network is determined, using facility location models, the alignment of the network needs to be addressed. Typical models that deal with this alignment and relevant for the scope of our research are inventory models that can be used to determine the deployment of inventory in the network. A company may hold inventories of raw material, parts work in progress, or finished products for a variety of reasons: to create buffers against uncertainties of supply and demand and buildup of reserves for seasonal demands or promotional sales; to take advantage of lower purchasing and transportation costs associated with high volumes, or economies of scale associated with manufacturing products in batches, and to accommodate products flowing from one location to another (work in progress or in transit).

When deciding when to order, the literature distinguishes between two ways of monitoring the inventories: continuous and periodic review. In addition we can identify between *order-up-to* and order quantity policies, single and multi-item, and single echelon and multi echelon. Key references on these types of models are Silver *et al.* (1998), Scarf (2002), Smits (2003).

Models for optimizing inventory policies for individual items use methods from statistics and applied probability theory. As such, they are very different in form from deterministic optimization models, which broadly consider products, facilities, and transportation flows when analyzing resource acquisition and making allocation decisions. Inventory models involve parameters and relationships, such as variance in market demands and delivery times and their impact on stock outages, which are not easily represented in optimization models. For this reason, incorporating inventory decisions in supply chain optimization models is very difficult. Nevertheless, depending on the scope of the analysis, acceptable approximations of

inventory costs can be developed. The number of published papers on inventory is vast, with numerous books dedicated to the subject (Sussams 1995; Graves and Dekker 2004).
Harris (1915) is often credited with the derivation of the economic order quantity (EOQ), but many people have worked in this area, including Wilson (1934) who made notable contributions. Initially, standard EOQ methods (Arrow *et al*. 1958; Magee and Goodman 1967) were used to evaluate costs inter-dependencies on networks that involve only direct shipping. Blumenfeld *et al.* (1985) consider transportation costs explicitly. The EOQ assumes that shortage costs are so high that they are to be avoided, and it balances the unit cost, reorder cost and the holding cost. In particular, it looks for a compromise between small, frequent orders and large, infrequent ones. If small orders are placed, the average stock is low, but the frequency of ordering will become prohibitively expensive. If large orders are placed, the cost of placing them is low, but high stock levels will raise investments. In our framework we will incorporate the integral costs and therefore we will implement an inventory model in accordance with the methodology of Blumenfeld *et al.* (1985).

4.3.3 Service network design

The validity of most logistics modeling depends on the correct understanding and realistic interpretation of the underlying cost structures. This is particularly true in the case of transport, where it is too easy to rely on published tables or readily computed averages. In practice, factors such as the age of the vehicle fleet, the utilization of capacity and the shift arrangement in use have a significant effect on unit costs and on the way these costs may vary from one scenario to another. The literature on service network design is vast and it is virtually impossible to describe all the different types and techniques used in this field of modeling (Crainic 2002; Savelbergh *et al*. 2004).

An excellent example of a typical network design model is presented by Crainic *et al.* (1984), which integrate the service network design and traffic multimode routing problems. The objective is to minimize the cost and increase the service performance of the system. This design problem is closely related to our network design problem, but the calculation of the number and locations of the hubs/terminals is not included in these types of models.

A service network specifies the transportation services that could be offered to satisfy the demand set by customers. Each service in this structure is defined by the route it follows through the physical network from its origin to its destination, by the sequence of intermediate terminals, and by its service characteristics: mode, speed, capacity, etc. The frequency λ_s is the other important service characteristic. It defines the level of service on the route: how often is the service run during the planning period. The items moved, following predefined itineraries, specify the path, the sequence of intermediate terminals or hubs on this path where operations are to be performed and the time-aspects of the service. The routing of shipments (or distribution), as given by the amount of flow (d_{ijb}) of product type b , on OD-relation $i \rightarrow j$, is also determined by the model. Frequencies and itineraries are the central elements of this type of model. Fixing frequencies values determines the design of the service network, the level of service and the feasible domain for the traffic distribution problem. On the other hand, the selection of the best itineraries for each product and OD-relation solves the traffic distribution problem and also determines the workload and the general consolidation strategies for each terminal of the system.

While solving the resulting mathematical programming problem, trade-offs between the cost of increasing the level of service and the extra costs of insufficient capacity may be addressed. Generally, one attempts to include those that reflect the cost and delay characteristics of the terminal and line operations most significant for the system. Typically for a LTL application one may have the costs and duration related to loading and unloading shipments at terminals, costs and delays due to cross-dock operations and consolidation function at the terminal, waiting for departure and, sometimes, for an unloading gate to become available, and the cost and time required to move vehicles and shipments to another gate.

More formally, the main decisions modeled using this type of model concern the following issues: (1) *service network design*, selection of the routes (origin and destination terminal, physical route and intermediate stops) on which services will be offered and the determination of the characteristics of each service, particularly their frequency; (2) *traffic distribution*, routing specification for traffic of each origin and destination pair (usually according to the specific commodity), services used, terminals passed through and operations performed at the terminals; (3) *terminal policies*, efficient allocation of work among terminals is an important objective, and terminal policies include general rules specifying for each terminal the type of consolidation performed; and (4) *empty balancing*, how to reposition empty vehicles to meet the forecast needs of the next planning period.

These problems and decisions have network-wide impacts and are strongly and complexly interconnected both in their economic aspects and their space-time dimensions. Thus, the strategies developed for different planning problems interact and mutually influence each other. Furthermore, trade-offs have be made between operating costs resulting from a given policy and the service quality, measured, in most cases, by delays incurred by freight and rolling stock, or in respect to predefined performance targets. These trade-offs are important when a single problem and decision is considered and even more so when the relationships between decisions or different problems is contemplated.

These service network design models usually involve both operating costs and service criteria. See Crainic (1988), for a comprehensive review of network, yard and line models, and Delorme *et al.* (1988) for a similar review of models and methods for LTL transportation. Interesting contributions to the field are found in Farvolden and Powell (1994) and Powell and Sheffi (1989).

4.3.4 Vehicle routing models

Another model type that is relevant for our framework is the class of *vehicle routing models.* The models just described typically relate to long distance freight transportation, where sorting and consolidation occurs at freight terminals. The next planning level takes place in more restricted geographical areas. It involves the distribution of goods at the local or regional level and comprises activities such as pick-up, delivery, or a combination of both. Vehicle routing problems have been extensively studied by operations researchers over the last forty years. Interesting references are those of Eilon *et al.* (1971), Bodin *et al*. (1983), Golden and Assad (1988), and Daganzo (1991). Such problems are generally referred to as *Vehicle Routing Problems*, but this designation covers a wide range of setups rather than a specific problem. Several versions of the problem can be defined, depending on a number of factors, constraints, and objectives. For instance, does the problem involve deliveries, collection or a combination of both? Does distribution take place from a single depot or from several centers? How many vehicles are involved? Is the demand known in advances? These are just some of the questions that must be addressed when solving a VRP (Uil and Groothedde 2004).

4.3.5 Integrative network design models

Logistics network design problems involve strategic decisions which influence tactical and operational decisions (Crainic and Laporte 1997). In particular, these problems involve facility location, inventory decisions and transportation, which affect the cost of the distribution system and the quality of the customer service level. So, they are in fact the core problems of each company. For example, location decisions, such as the number and the location of facilities, the assignment of facilities to supply sources, and the allocation of demand to facilities, affect inventory decisions, such as the total inventory and the location of these inventories, Vice versa, inventory decisions affect location decisions. Inventory decisions also affect transport decisions, and, vice versa, transportation decisions, such as the mode and the type of carriage, in their turn influence inventory decisions. As emerged from the discussion above, logistics network design problems involve a lot of integrated decisions, which are difficult to consider all together when solving the problems. Generally, some simplifying assumptions have been adopted in the literature for dealing with logistics network design problems, and only some aspects related to the complex network decisions have been incorporated into models.

In addition to representing facility location, vehicle routing and scheduling, fleet selection and inventory management, House and Karrenbauer (1982) argue that logistics models should account for the following characteristics: (1) the dynamic and evolutionary nature of logistics systems, (2) the stochastic nature of inputs and uncertainties to such models, (3) non-linear costs, (4) multiple objectives of the firms, (5) multiple products, (6) multiple inventory echelons and (7) capacity restraints on components of the system. They conclude: "*there is yet no universal model capable of dealing with all variables, all situations and all possible scenarios*".

Ambrosino and Scutellà (2001) present several distribution network design models which involve facility location, warehousing, transportation, and inventory decisions. Several realistic scenarios are investigated. The warehouse locating-routing model is particularly relevant in the context of our objective. This problem consists of determining the number, size and location of the warehouses, the allocation of the customers to these sites, the direct replenishment of the warehouse, and the delivery tours for serving the customers from the warehouses, so as to minimize the sum of the transportation and the warehousing costs.

One of the important open issues in logistics is the effective integration of logistics costs components such as transportation, inventory and warehouse costs with facility location models, since these are highly inter-dependent. The determination of optimal values of these variables is crucial for minimizing physical distribution costs. An important contribution was provided by Syam (2002), who presented a model for the location problem with logistical components. Syam proposed an integrated location-consolidation model and provided two sophisticated methodologies to solve the problem: langragian relaxation and simulated annealing. The primary objective is closely related to our objective and was the development of a model and solution methodologies that permitted the simultaneous determination of: (1) optimal plant locations, (2) optimal flows in the resulting distribution network, and (3)

optimal shipment compositions and frequencies in the network, taking into account the relevant logistical costs such as warehousing costs, transportation costs, and handling costs.
Another important issue that needs to be addressed by an integrative approach is the fact that there are multiple objectives and multiple products in a logistics network. The framework considered in logistics network design is usually that of single objective optimization. In contrast Dong *et al*. (2002) focus on both the multi-criteria and multi-tiered aspects of logistics networks with an eye towards understanding the underlying behavior of the various decision-makers and their different roles within this network of actors. To date, except for recent work of Nagurney *et al*. (2002), the subject and theory of multi-criteria decision-making in the logistics network context has focused exclusively on either the production side or on the consumption side, and, typically, has considered only a single decision-maker (Chankong and Haimes 1983; Yu 1985; Keeney and Raiffa 1993). In the context of facility location Current *et al.* (1990) focus on the multi-objective analysis of facility location decisions. For key contributions on the configuration of a logistics network with multiple suppliers see Kim *et al.* (2002), on strategic network design De Kok and Graves (2004), on the incorporation of inventory control decisions into a strategic distribution network design Miranda and Garrido (2004) and Shen *et al*. (2003).

4.4 Simulation models

Simulation allows one to estimate the performance of a given system under some projected set of operating conditions. Alternative network solutions (or alternative operating policies for network solutions) can be compared via simulation to see which best meets a specified requirement. With simulation we can maintain much better control over the experimental conditions than would generally be possible when experimenting with the system itself. Simulation allows us to study a system with a long time frame — e.g. an economic system — in compressed time, or alternatively to study the detailed workings of a system in expanded time. Each run of a stochastic simulation model produces only estimates of a model's true characteristics for a particular set of input parameters. Thus, several independent runs of the model will probably be required for each set of input parameters to be studied. For this reason, simulation models are generally not as good at optimization as they are at comparing a fixed number of specified alternative system designs. On the other hand, an analytic model, if appropriate, can often easily produce the exact true characteristics of that model for a variety of sets of input parameters. Thus, if a valid analytic model is available or can easily be developed; it will generally be preferable to a simulation model. In our modeling framework both types of models are useful. Simulation can be used to check the validity of assumptions needed in an optimization model. On the other hand, an optimization model can suggest reasonable alternatives to investigate in a simulation study. We use discrete-event simulation to model logistics systems and network solutions.. Banks (1998) states that simulation is the imitation of a real world system over time and includes the generation of an artificial history of the system and the observation of that history to draw inferences concerning the operational characteristics of the system-being-modeled. Simulation is widely used within the field of logistics (Ebben 2001; Rohrer 1998) and transportation (Manivannan 1998; Babeliowsky 1997). Banks (1998) and Law and Kelton (1991) offer an overview of the benefits of using simulation as a research approach. We refer to simulation because the systems studied do not yet exist and simulation is a powerful tool for studying systems that are not available in practice. Choosing simulation software is an important aspect of simulation studies. In practice many different simulation software packages exist that can be used to construct simulation models (Swain 1999). Nikoukaran *et al.* (1999) provide a comprehensive list of criteria for the selection of suitable simulation packages. Law and Kelton (1991) provide a list of desirable features that simulation software needs to offer. The criteria offered by Nikoukaran *et al*. (1999) and Law and Kelton (1991) are general criteria for selecting simulation software

In addition to analyzing decision policies, deterministic simulation models can assist managers in understanding complex interactions among system states, data, and decision variables. For example, due to lag and feedback effects in a manufacturing environment, work-in-process inventory may experience volatile and costly oscillations. A better qualitative understanding of the causes of these oscillations could lead to improved operations. A deterministic simulation model could indicate the extent to which the stability of a manufacturing system depends on reducing the variance of delivery time between manufacturing stages, on improving the accuracy of demand forecasts for finished products, or on other means.

4.5 Discussion

In this chapter we discussed different approaches and methodologies to modeling the different decision-making processes associated with logistics network design. The design problem we focus on was briefly discussed and to address this design problem we examined facility location models, inventory models, service network design, vehicle routing, and integrative approaches (network design). In addition we briefly discussed discrete simulation models as this is a very powerful tool when evaluating logistics network solutions and enables us to assess the reliability and robustness of the network solutions derived from the network design procedure.

These different levels of decision-making discussed have network-wide impacts and are strongly and complexly interconnected both in their economic aspects and their space-time dimensions. Thus, the strategies developed for different planning problems interact and mutually influence each other. Furthermore, trade-offs have to be made between operating costs resulting from a given policy and the service quality measured. These trade-offs are important when a single problem and decision is considered and even more so when the relationships among decisions or different problems are contemplated. Therefore decisions should be made globally, network-wide, in an integrated manner. This complexity has been the subject of a growing body of literature, as we have seen in this chapter and the associated research being both conceptual in nature, due to the complexity of the problem and the numerous actors, such as retailers, or consumers involved in the transactions, as well as analytical. We primarily focus on an integrative approach to derive the structure of the logistics network (using facility location techniques), to derive the alignment of the network (using inventory models), scheduling of the network (using service network design models), and resource deployment (using vehicle routing algorithms). In addition, as we will see in Chapter 6 and Chapter 7 we will incorporate multiple actors and multiple objectives.

5 The integral costs in logistics network design

In this chapter we will discuss the key component in the logistics network that we need to take into account when designing hub-networks. The key trade-offs will be discussed, followed by a discussion on hub-network design. Based on the state of the art, we will work towards a framework for the design of collaborative networks. As we will design and evaluate a logistics networks, based on costs and performance, it is imperative to be able to tabulate the costs of the starting network (current situation).

Logistics is a classic example of a systems approach to business problems. From a company's point of view the systems approach indicates that the company's objectives can be realized by recognizing the mutual inter-dependence of the basic functional areas of the firm, for example marketing, production, and finance. The objectives of business logistics encompass efforts to coordinate physical distribution, materials management and inbound logistics in order to reduce costs and/or improve the service. To achieve these objectives it is necessary to use an integral costs approach as there are important trade-offs between these different costs components. For example, a reduction in transportation costs could well mean that the inventory costs increase due to large shipment sizes. An improvement in order lead-time could well lead to a considerable increase in transportation and handling costs. It is therefore of great importance, when designing a logistics network, to use the integral costs and base the decisions on all aspects of the logistics network (structure, alignment, scheduling, and resources) on the integral costs and service performance. This approach is built on the premise that all relevant functions in moving, holding, handling, and administering materials and products should be considered as a whole, not individually. These integral costs may include a number of terms such as the following: raw material acquisition costs, inbound transportation costs, facility investment costs, manufacturing costs, warehousing costs, inventory holding costs, outbound transportation costs, handling costs, order processing. In addition, we introduce the transaction and governance costs that need to be taken into account (see Chapter 6). This chapter describes how to account for various costs arising from a logistics operation; it introduces related terminology and notation. This will be done in the context of a single origin producing identical items for a single consuming destination. The formulas and concepts extend to the more general networks examined in the later chapters of this thesis. Before we will address these key trade-offs in logistics we will first elaborate on the different techniques that are available, to gain an insight into the integral costs. We will only touch on this aspect but it is important to realize that in order to assess the improvements and extensions of the logistics network we will derive using our framework, it is imperative to be able to have a clear understanding of the costs of the current logistics network.

5.1 Measuring the logistics costs

The whole purpose of logistics strategy is to provide customers with the level and quality of service that they require and to do so at less cost to the total logistics network. In developing a market-driven logistics strategy, the aim is to achieve a high level of service in a consistent and cost-effective way. After a century or more of reliance upon traditional costs accounting procedures to provide an often unreliable insight into profitability, managers are questioning the relevance in logistics of these methods (Johnson and Kaplan 1987). The accounting framework still used by the majority of companies today relies upon arbitrary methods for the allocation of shared and indirect costs and hence frequently distorts the true profitability of both products and customers. Because logistics management is a flow-oriented concept with the objective of integrating resources across the logistics network which extend from suppliers to final customers, it is desirable to have a means whereby costs and the performance of that network can be assessed. Probably one of the main reasons that the adoption of an integrated approach to logistics has proved so difficult for many companies is the lack of appropriate cost information. The need to manage all the activities in the network as a complete system, having regard for the effects of decisions taken in one cost area upon other cost areas, has implications for the cost accounting systems of the organization. Typically, conventional accounting systems group costs into broad, aggregated categories which do not allow the more detailed analysis necessary to identify the true costs of servicing customers with particular products.

Companies often lack useful tools to support decisions regarding their logistics operations with cost information. There are several possible explanations for this shortcoming. Traditionally, logistics has been of minor interest to most companies. Attention was focused on the manufacturing of products according to specifications. In addition, accounting methods are based on assumptions of a stable and predictable market, long product life-cycles, large production runs and a large portion of direct, variable costs in total production costs. But these assumptions are no longer true, as has been illustrated in Chapter 2. Finally, most research projects, aimed at the development of new cost allocation and decision support techniques thus far, have been limited to manufacturing environments (Van Damme 1999). The problem of the lack of tools able to determine costs in the logistics network has been recognized since 1940. Since then different techniques and approaches have been developed. Here, we limit ourselves to three techniques (*Direct Product Profitability*, the *Cash flow Approach* and *Activity Based Costing*) to calculate and allocate the costs, which we will briefly discuss before continuing with the key trade-offs in logistics. By focusing on these three approaches we stress the importance of being able to accurately assess the performance, in costs and performance of the logistics network, especially when comparing the network solution derived from the network design algorithm, like the one we will present in the following chapters.

5.1.1 The Cash Flow Approach

The first approach we discuss here is the cash-flow approach, where those cash flows that can be altered by taking the right business decisions are centralized. This can be seen as a reaction to a poorly-functioning cost understanding. If the economic aspects are balanced against the evaluation of results, it is only the outcomes of realistic cash flows that need be taken into consideration. These are the cash flows of a company consist of an outgoing flow on the side of the supplier's market, and an incoming flow on the side of the customers' market with no internal cash flow present. The economic result of a specific decision is defined as the balance of incoming and outgoing money flows. Money flows are viewed in terms of the total decision horizon, without splitting up the time frame into reporting periods. The difference from the traditional cost approach is noticeable at the operational and tactical level. Moreover, by making decisions at the strategic level, most of the production factors, and consequently most of the costs, become variable. Then the difference between costs and expenditure disappears. For more information on this technique we refer to Van Damme (1999).

5.1.2 Direct Product Profitability

Direct product profitability is a method of planning variable markups by determining the profitability of the individual item or classification of merchandise by calculating the adjusted per unit gross margin and assigning direct product costs to the item for expenses like distribution and selling. Direct product profitability (DPP) represents the first significant effort to determine the costs of moving products through an entire logistics network. The retail sector initiated DPP as a pricing technique during the 1960s and 1970s, to provide a technique to identify the profit contribution of individual products by taking into account specific handling and space costs incurred by an item (AC-Nielsen 2003).

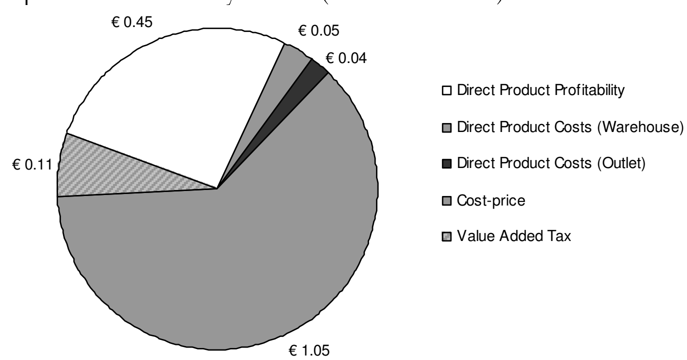

Figure 5-1: Product price buildup (euro/item).

DPP provided a significant advantage over traditional accounting practice for food retailers. Retailers had traditionally relied on gross profit and gross margin for measuring performance. DPP supports decisions in three ways: (1) it provides insight into the real profit contribution of various products. This information is particularly interesting for the purchase and sales departments, (2) it provides information relating to the existing cost composition of physical flows. This information is used to identify activities that are relevant for the costs, and is subsequently used for optimization purposes, and (3) it provides insight into the overall costs implications of different logistic alternatives. Figure 5-1 presents an illustration of DPP. With DPP, retailers can identify the specific warehouse and retail costs associated with moving each item through the distribution system from the time it is received from the supplier to the point the consumer takes the product from the store. If adopted, DPP can ultimately replace gross margin calculations as a yardstick for measuring profitability.

5.1.3 Activity Based Costing

Activity Based Costing (ABC) is an accounting technique that allows organizations to determine the actual costs associated with their services based on the resources they consume. This technique can be used in a variety of ways, including targeting high-cost activities, forecasting financial baselines, and supporting resource allocation. Activity Based Costing (ABC) emerged during the 1980s as a means to more accurately assign costs within an organization. It is a technique for assigning the direct and indirect costs of an organization to the activities consuming the organization's resources and then subsequently traces the costs of performing these activities to the products, customers, or distribution channels consuming the activities. All costs are assumed to vary in direct proportion to the allocation basis.

However, indirect costs frequently do not vary in direct proportion with labor hours, machine time, or material consumption. ABC recognizes the different relationships and uses multiple drivers to trace the consumption of indirect resources to the activities consuming them. ABC goes one step further by tracing the activity costs to objects consuming the activity costs. Firms using ABC can obtain more accurate information of how specific products, customers, or supply chains affect costs and contribute to overall profitability (Fuller *et al.* 1993). ABC has gained considerable attention as a potential tool for evaluating supply chain performance. See for example Van Damme (1999) for additional methodological information and case studies. When involved in collaborative logistics it is imperative that the costs are made transparent and the added value of a participant can be pinpointed. This is the main reason why we focus on ABC, because the activities, resources and costs can be located and accurately distributed across the different participants. Here we limit ourselves to the description of the basic steps that can be distinguished in ABC that in a logistics network context usually employs basically five steps:

(1) Analyzing the logistics network processes. A detailed description and breakdown of the logistics processes that are under investigation needs to be made.

(2) Breaking processes down into activities. When the process description is made, the activities that make up the processes need to be identified and described.

(3) Identifying the resources required to perform an activity. When the activities are listed the next step is to tabulate the resources required to perform the activities in the logistics network.

(4) Costing the activities. Based on the required resources, and their costs, the cost of the different activities can be calculated.

(5) Tracing the activity costs to logistics network outputs. Finally, when the activities and the required resources are listed, using the appropriate cost-drivers, it is possible to assign the different costs to the different processes, activities, and/or customers.

In section 1.2 we presented the different activities we distinguish in our logistics network. These activities form the basis of our cost calculation, used in the network design algorithm. If, next to these activities, the resources required to carry out these activities are listed, the costs can be accurately assigned to, for example, the different users of the network. With better information and accounting systems, firms are beginning to disaggregate revenues and costs to customer or account level. This analysis often reveals previously hidden subsidies across customers, products, and markets. Most firms are well aware of the 80/20 rule in which a small fraction of customers accounts for a large share of revenues and most of a firm's profits.

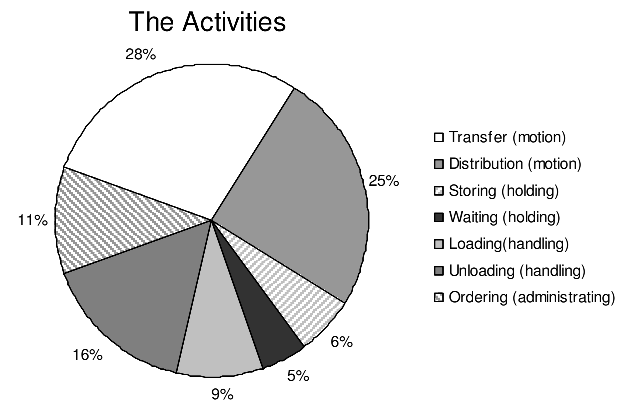

Figure 5-2: Costs per resource (example).

A small fraction of profitable customers subsidizes the firm's other unprofitable or, at best, breakeven customers. Instead of accepting the 80/20 rule, firms should strive to identify those subsidized customers and work with them in either altering the servicing of those customers (including pricing) to a more equitable arrangement or outsourcing the servicing of those customers altogether.

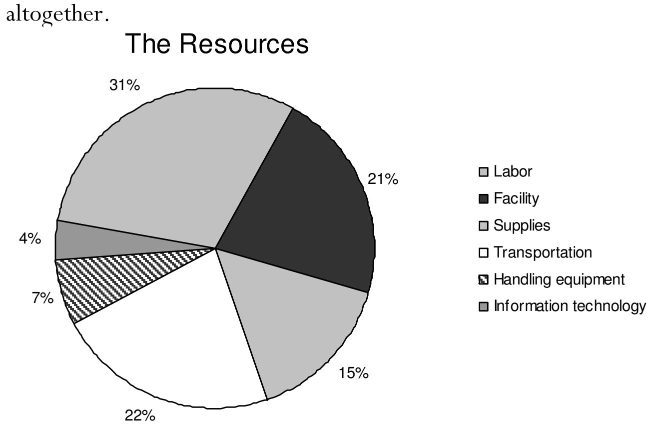

Figure 5-3: Resources needed to carry out the activities (example).

In Figure 5-2, Figure 5-3, and Figure 5-4 an example of this activity-based costing methodology is presented. In these three figures the activities, the resources, and finally the assignment of the costs to the different customers is illustrated. By making these costs explicit it is possible to calculate the individual cost an individual user induces and what the added value is of a specific participant. This capability is crucial to be able to assess the performance of the starting network, in terms of costs and service, and to be able to analyze the key trade-offs in the logistics network costs versus service for the new network solution. Finally, in collaborative networks, the added value or costs of a participant needs to be measurable and the costs need to be properly assigned. A technique capable of doing this is, in these types of networks, paramount. Additional gain-sharing techniques should also be adopted in order to distribute not only the costs but also the benefits.

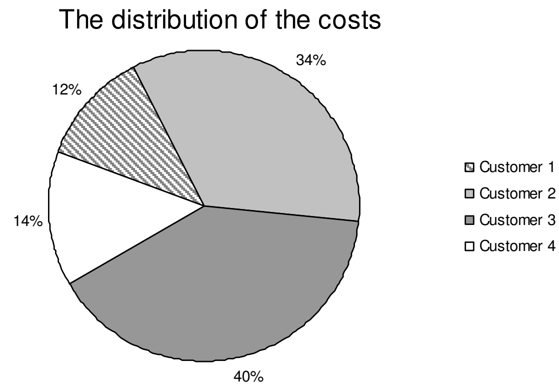

Figure 5-4: Distribution of the costs to the customers (example).

In Table 1 an example is provided of the distribution of the resources per activity. In this example we distinguish 8 different activities (order picking, loading, transfer, etc.) and in the columns of the table the resources needed to carry out these activities are presented. For example, 120 man-hours a month are needed, 418 vehicle-hours/month for the transfer, and 200 m^2 for order administration. Then, in the final column (costs per activity) the associated costs per activity in €/month are presented. This methodology allows us to lust the costs per activity and in addition list the resources needed.

Table 1: Distribution of the resources per activity.

	Resources				
Activities	Labor (man-hours/month)	Equipment (vehicle-hours/month)	Footprint (m^2)	Equipment (vehicle-hour/month)	Costs per activity (€/month)
Orderpicking (handling)	120	-	200	174	€5,452
Loading (handling)	96	-	400	139	€5,022
Transfer (Motion)	312	418	-	-	€21,079
Crossdocking (Handling)	231	-	600	335	€11,086
Distribution (Motion)	378	585	-	-	€28,217
Order transmitting (Administrating)	98	-	200	-	€2,706
Order receiving (Administrating)	78	-	200	-	€2,266
Order administrating (Administrating)	120	-	200	-	€3,190
Total	1433	1003	1800	648	-
Costs per resource	€31,526	€34,115	€4,950	€8,426	€79,017
Cost assignment					
Customer A (35% of orders)	€11,034	€11,940	€1,733	€2,949	€27,656
Customer B (25% of orders)	€7,882	€8,529	€1,238	€2,106	€19,754
Customer C (40% of orders)	€12,610	€13,646	€1,980	€3,370	€31,607

The final step, consists of the distribution of the costs per activity to the different customers. This distribution can be based on the volume, number of orders, shipments, etc. per individual customer. In our example we assume that the costs can be assigned using number of orders.

In our network design methodology we will make use of this technique for every new network solution. Generated by our design algorithm, the activities in the network are listed, the required resources are tabulated and the utilization of these resources calculated, then finally the costs are assigned to the users of the network. In the next section we will elaborate on the basic trade-offs present in the logistics network before we address the state of the art of hub-network design (see section 8.2 for an application of this technique).

5.2 Basic trade-offs in a logistics network

During the path of an item from production to consumption it must be handled from the production site to a storage area, where it is held with other items, where they wait for transportation, are loaded into a vehicle, shipped to the destination and unloaded, handled and finally held at the destination for consumption. These activities, on which we focus in this chapter, incur costs related to either *motion* (overcoming distance) or *holding* (overcoming time), handling, and administration (see section 1.2). For example, holding costs include warehousing costs and inventory costs. Warehousing costs consist of the rent for the space and equipment needed to store the items, and additional maintenance costs, such as security, utility and insurance directly related to the storage space Inventory costs are meant to capture the costs of delay to the items, including the opportunity cost of the capital tied up in storage and any value lost while waiting or during shipment. In the following sub-sections the different cost categories will be examined and quantified, with the aim to identify which parameters influence the various costs and the mathematical form of the relationships. These sections are based on Daganzo (1999) and Blumenfeld *et al.* (1985).

5.2.1 Inventory and warehousing costs

A sufficiently quantitative description of inventory and warehousing costs can be given in the context of a simple scenario with one origin and one destination relation, depicted in Figure 5-5. The four curves of the figure represent the cumulative number of items that have been: (1) produced, (2) shipped, (3) received at the destination, and (4) consumed. Rarely used in the inventory and queuing literature, cumulative count curves such as those depicted in the figure above are particularly useful to trace items through consecutive stages. In this specific case, they conveniently describe in one picture how the number of items present in various logistical stages changes with time. For example, the number of items waiting for transportation at any given time is the vertical separation between curves (1) and (2) at the corresponding point on the time axis; the number being transported is the vertical separation between curves (2) and (3); and the number waiting for consumption is the vertical separation between curves (3) and (4).

For additional measures of performance that can be read from these curves see Newell 1983 and Daganzo 1999. . When items pass through the system in a first-in-first-out order, as in Figure 5-5, then the n^{th} item to be counted at each observation stage (1,2,3,or 4) is the same item. In Figure 5-5, the n^{th} item is produced at t_1, shipped at t_2, it arrives at the destination at t_3, and is consumed at t_4. As a result the horizontal separation between any two curves at ordinate n represents the amount of time spent by that item between the corresponding events. In Figure 5-5, thus, t^m represents the transportation time. The shaded area between curves (1) and (2) in the figure represents the number of *item-hours* spent at the origin, while the cursive shaded area between curves (3) and (4) represents the item-hours waited at the destination. The production and consumption rates are assumed to be constant and equal to P' .

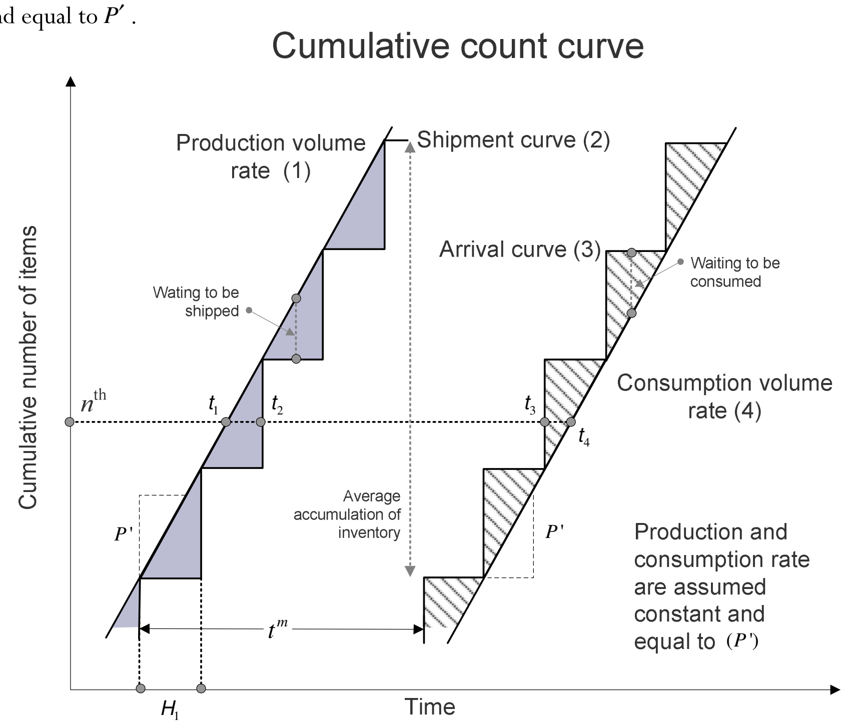

Figure 5-5: Cumulative item counts at different stages in the logistics operation. Adapted from Daganzo (1999).

It follows that the average horizontal separation between two curves represents the average time that a typical item spends between the events represented by the curves. In our example, the constant separation between the production and consumption curves represents the average *waiting* of an item between production and consumption. This is equal to t^m plus the maximum interval (or headway) between successive dispatches, $H_1 = \max\{H^{max}\}$:

$$t^w = H^{max} + t^m \tag{5.1}$$

The inventory costs are associated with delay to the items. As is commonly done in the inventory literature, it will be captured by the product of the delay experienced by all the items and a constant representing the penalty paid for holding one item for one time unit. Thus,

$$c^{inv} = \pi\rho \cdot [H_1 + t^m] \tag{5.2}$$

In which c^{inv} represents the inventory cost (€/item), ρ the interest rate, π the value of the item (€/item), and the term in brackets the waiting between production and consumption. Because the expressions implicitly value all the item-hours equally, caution must be exercised when the penalty depends on: (1) the time of day, week or year when this wait occurs, and (2) how long a specific item has already waited. The total inventory costs, based on the production volume rate P', and inventory costs c^{inv}, can be stated as follows:

$$C^{inv} = c^{inv}[P'(H_{1+}t^m)] \tag{5.3}$$

The term in brackets in expression (5.3) represents the average accumulation of inventory in the system (the vertical separation between the production and consumption curves of Figure 5-5). For perishable items, and items exposed to loss and damage, (5.2) should also include any value losses arising from time spent in the system. Next to the inventory costs, costs for warehousing are incurred. These costs depend on the size of the items, their storage requirement and the prevailing rents for space. We simplify this by formulating the warehousing costs (€/item), denoted c^{wh}, as follows:

$$c^{wh} = (C^{whl} + C^{whf} + C^{whh})/Q \tag{5.4}$$

where the annual labor costs are denoted as C^{whl}, the annual costs of the investment storage space C^{whf} and the costs in €/year incurred for the handling equipment as C^{whh}. The sum of these cost aspects are then divided by the annual throughput of the warehouse Q (items/year). It is usually convenient to group the terms associated with H_1 in equations (5.2) and (5.3) by defining a stationary holding cost per item-hour ($c^h = c^{inv} + c^{wh}$).

5.2.2 Transportation costs

Next to the costs for warehousing and inventory, the costs for transportation are introduced, again in the context of the origin-destination relation (OD-relation) depicted in Figure 5-5. If one uses a carrier to transport items from an origin to a destination, the total costs per year will usually be the sum of the costs of each individual shipment. The rates usually increase in steps, but the overall slope is approximately constant for wide ranges of shipment sizes. The mathematical relationship is:

$$c_{ij} = c^f + c^v v \tag{5.5}$$

where v is the shipment size, c^f is a fixed cost per shipment that should include labor costs, and c^v is the rate at which the variable costs per shipment increases with size. The cost for shipping a sequence $\{v_i\}$ of n shipments ($i = 1,...,n$) totaling V items ($V = \sum(v_i)$) is thus:

$$C_{ij} = \sum_{i=1}^{n}\left(c^f + c^v v_i\right) = c^f n + c^v V \tag{5.6}$$

The total cost C_{ij} only depends on the number of shipments n, regardless of what they contain and when they happen, and the total number of items shipped V. The cost per item, thus, decreases with the average shipment size $\bar{v}$.

$$c_{ij} = c^f\left[\frac{n}{V}\right] + c^v = c^f\left[\frac{1}{\bar{v}}\right] + c^v \tag{5.7}$$

These economies of scale arise because all the items in a shipment share the fixed costs, c_f. For this simple example with one origin and one destination, the only decision variable appearing in equation (5.7) is n (or $\bar{v}$); thus, the variable cost should not influence shipping decisions. It will not be eliminated in this expression, though, because c^v is not a constant for more complicated problems. As we shall see, c^v depends on distance; and for problems with many origins and destinations, the distance traveled is not fixed. Published rates reveal that c^f and c^v depend mainly on distance (or time); the precise location or origins and destinations also influence these costs but to a lesser extent. The relationships are well approximated by linearly increasing functions of distance, denoted by *l*:

$$c^f = c^s + c^l l_{ij} \tag{5.8}$$

$$c_v = c'_s + c'_l l \tag{5.9}$$

The interpretation of these four new parameters appearing in the right-hand side of these expressions (5.8) and (5.9), is easier when the above expressions are substituted for c^f and c^v in equation (5.6). The cost for *n* shipments totaling *V* items, when the origin and destination are l_{ij} distance units apart, can be broken up into four terms as follows:

$$C_{ij} \approx c^s n + c^l n l_{ij} + \dot{c}^s V + \dot{c}^l l_{ij} \tag{5.10}$$

The first parameter, c^s, is the cost attributable to each trip, regardless of distance and shipment composition; it includes the cost of stopping the vehicle and having it sit idle while it is being loaded and unloaded.

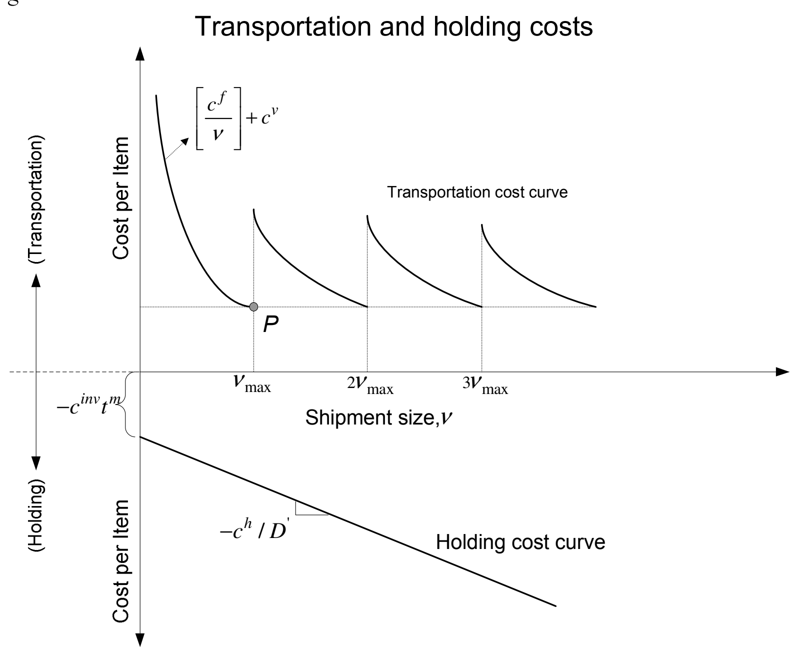

Figure 5-6: Transportation and holding costs (per item) as a function of shipment size

Think of it is as the fixed cost of stopping, independent of what is being loaded and unloaded (also referred to as call-out charge). The second parameter c^l, is the cost attributable to each incremental vehicle kilometer. It is the vehicle costs (including the driver) for each kilometer regardless of the vehicle's contents. The third parameter, denoted $\dot{c}^s$, represents the added cost of carrying an extra item. It represents a penalty for delaying the vehicle while loading and unloading the item. The fourth parameter $\dot{c}^{l}$ is the cost attributable to each incremental item-kilometer. It can be viewed as the marginal wear and tear and operating cost per kilometer for each extra item carried. So far, the possibility of sending shipments that would not fit in a single vehicle is ignored. If one were to plot the cost per item versus the shipment size for a range extending beyond this maximum, $v_{\max}$, for a firm that runs its own vehicles, a graph as shown in Figure 5-6, would probably be found. Whenever the shipment size reaches and exceeds a multiple of $v_{\max}$, a new vehicle needs to be dispatched with a resulting jump in cost. The figure also plots the negative of the holding costs as a function of shipment size (assuming that the headways are regular and equations (5.3) and (5.4) are used with $H_1 = H = v / D'$ and $c^h = c^{inv} + c^{wh}$.

The optimal shipment size is the value v for which the vertical separation between the two curves of Figure 5-6 is minimal. This point can be easily found by sliding the *waiting* curve upwards until it first touches the transportation curve. This can only happen either at point *P* of the figure (where $v = v_{\max}$), or else at point $v < v_{\max}$, if the line is sufficiently steep. For most problems, thus, one can ignore the behavior of the transportation curve for $v > v_{\max}$. This is the well known *lot size* or *economic order quantity* (EOQ) model of the inventory control literature discussed earlier (section 4.3.2). Analytically, the optimal shipment size of Figure 5-6 is the solution of the following problem:

$$\text{Minimize } \frac{c^h}{D'}v + \frac{c^f}{v} \tag{5.11}$$

subject to:

$$v \le v_{\max} \tag{5.12}$$

5.2.3 Handling costs

Handling costs include loading individual items on to a load-unit, moving the load-unit to the transportation vehicle threshold, and reversing these operations at the destination. The container can be a box, pallet or container, or if the items are large enough no separate load-unit is used. Here the cost of handling a shipment of size v , is examined. If the items are handled individually, the handling cost per shipment should be proportional to v , so that the handling cost per shipment is:

$$c^u = c^{hv} v \tag{5.13}$$

If the items are small it is not economic to move them individually; instead they can be moved on load-units, such as pallets. Clearly, the handling cost should have a similar form as the transportation function, since items are being transported within the compound. If the batch is smaller than one pallet, the cost of handling it should therefore be:

$$c^u \approx c^{hf} + c^{hv} v \tag{5.14}$$

The parameter c^{hf} represents the (fixed) cost of moving the pallet regardless of what it contains, including the forklift driver's wages, plus the forklift's depreciation and operating cost. The parameter c^{hv} captures the cost, accounting for both labor and capital, of loading one item on the pallet. If v is larger than the maximum number of items that fit on a pallet, $v_{\max}^{u}$, then the handling cost function per shipment, $f^{h}(v)$ will still be a scaled down version of the transportation function. At the destination, the handling cost function will be analogous, possibly with different c^{hf} and c^{hv} but the same $v_{\max}^{u}$. Within an error of c^{hf} , the motion cost per shipment (transportation and handling) can be approximated by curve PQ Figure 5-7 which is a lower boundary:

$$f^{h}(v) \approx c^{f} + \left(c^{v} + c^{hv} + \frac{c^{hf}}{v_{\max}^{u}} \right) v \tag{5.15}$$

5.2.4 The optimal shipment size

If we pro-rate the cost of a shipment to the items that it contains, we can construct Figure 5-6, which can be used to determine the optimal size of the shipments. Figure 5-7 is not extended beyond $v_{\max}$, since larger shipments continue to be inefficient.

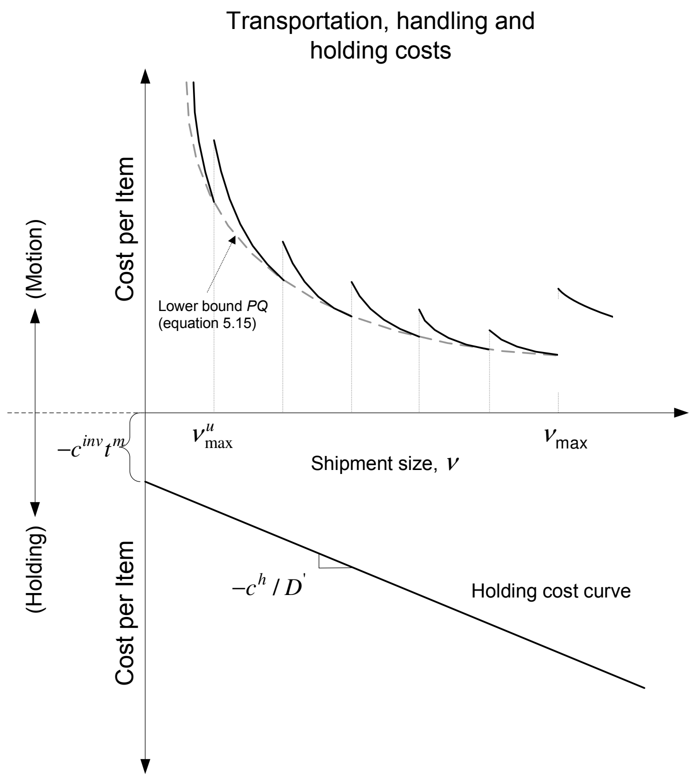

Figure 5-7: Motion and holding costs per item as functions of shipment size.

Note from the figure that if the waiting cost curve is pushed upwards, the first point of contact is either $v < v_{\max}^{u}$ (if the waiting cost curve is very steep), or else it is likely to be an integer multiple of $v_{\max}^{u}$. Because the lower bound from equation (5.15) is exact when v is an integer multiple of $v_{\max}^{u}$, one could use it instead of the exact (scalloped) curve, while restricting v to a multiple of $v_{\max}^{u}$. If the shipment size is restricted to an integer multiple of

$v^u_{\max}$, the optimal shipment size is independent of handling costs. If the optimal shipment size v^* is greater than one pallet, we see from Figure 5-7 that allowing v to differ from a multiple of a pallet cannot improve things appreciably. In the most favorable case the cost savings can be shown to be about one tenth of $c^f / v^u_{\max}$, with much smaller savings in other cases. If v^* is smaller than one pallet, then handling costs should be considered; there may be a significant difference between $f^h(v)$ and its lower boundary.

5.3 Network trade-offs

In the previous section some trade-offs between inventory, transportation and handling were illustrated. In this section we will illustrate the different types of networks that will be examined namely a network with direct shipment, shipment via a terminal, and a hub-network (Figure 5-8). Suppose each origin produces a unique product for each destination and that the destinations demand these products at constant rates. Transportation costs (i.e. the freight rates incurred to shipments on each link) are associated with all the origin-destination links. Inventory costs at the origin, on the links and the destinations result from products waiting to be shipped, in transit, and waiting to be used once they arrive. Production setup costs are associated with the manufacturing plants at the origin. All transportation, inventory, handling and production set-up costs associated with this network are considered simultaneously regardless of how these costs are allocated. To minimize the sum of these costs, optimal shipment sizes on each link and optimal production lot sizes for each product must be determined. Based on equations (5.18) and (5.19), the optimum shipment size can be derived. Let $z = \min\left[\left(c^h/D'\right)v + c^f/v\right]$, subject to $v \le v_{\max}$, and consider the case in which $v_{\max} = \infty$. Then v^* is the value of v which minimizes the convex expression $\left(c^h/D'\right)v + c^f/v$:

$$v^* = \sqrt{\left(c^f D' / c^h\right)} \tag{5.18}$$

Note that v^* is the value which makes both terms of the objective function equal. That is, for an optimal shipment size, holding costs equals motion costs. The optimum cost per item is:

$$z^* = 2\sqrt{\left(c^f c^h / D'\right)} \tag{5.19}$$

As a function of c^f , c^v and D' the optimum cost per item increases at a decreasing rate with c^f and c^v and decreases with the item flow D'. There are *economies of scale,* since higher item flows (D') lead to a lower average cost (z^*).

The second type of network we consider here is a network in which flows can be either sent directly from origin to destination or consolidated at a terminal in the network. Use of consolidation terminals to transport items from various origins to various destinations can take advantage of economies of scale in transportation costs. Instead of making direct shipments, each origin can ship in bulk to one or more terminals. There the shipments can be broken down, and different shipments can be combined into one. In this example we consider a freight transport problem. For each OD-relation, it must be decided whether to ship the products or send them via a consolidation terminal. When optimal shipment sizes are used on each link and no capacity restraints are present at the terminal, the cost per item is a concave function of flow, and the least cost strategy is always direct shipment or shipment via the terminal (Klincewicz 1990). Thus, only these two options are considered when deciding how to ship a part from origin to destination. The objective of this type of design problem is to minimize the total logistics costs by selecting the optimal network configuration in terms of the location and number of terminals. The design variables are the number, location, and the percentage of flow sent directly from origin to destination. In addition, capacity, scheduling of the service could be included in this type of design problem (frequency, routing, capacity, type of vehicles, etc.). If capacity restrictions are taken into account a mix between the two option discussed could be efficient.

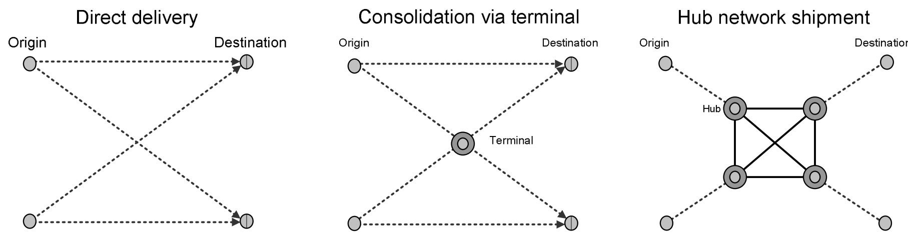

Figure 5-8: Network types.

The third type of network presented in this chapter is the hub network. Hubs, or central trans-shipment facilities, allow the construction of a network where large numbers of direct connections can be replaced with fewer, indirect connections. These hub network configurations reduce and simplify network construction costs, centralize handling and sorting, and allow carriers to take advantage of economies of scale. In the next section we will discuss this type of network in detail.

5.4 Hub network design

Hubs are frequently used in transportation and telecommunications systems. In such systems, various locations send and receive products, data, freight, packages. Instead of having each pair of locations exchange traffic directly, hubs can be established as intermediate switching points. Hub location research has become an important area of location theory over the last twenty years. These problems differ from classical facility location problems in several ways. In a classical discrete facility location problem, demand for service occurs at discrete points; facilities are located at discrete points and the objective is generally related to the distance or cost between the facilities and the demand points. In hub location problems demand is specified as flows between many origins and destinations, and hub facilities serve as switching (or connection) and consolidation (or concentration) points for the origin-destination flows. As a switching point, a hub allows flows to be redirected.

In addition, a hub may perform a consolidation or concentration function to combine many small separate flows into larger flows. Hubs may also perform the opposite function of splitting a large flow into separate smaller flows for different destinations. Thus, hubs are intermediate points along the paths followed by origin-destination flows. Transportation applications of hub networks include air-freight transportation, express shipments, parcel services, large trucking systems, postal operations and overnight delivery systems).

Below we listed the key dimensions of a hub-network design problem. The first two dimensions are the location and the number of the hubs to be located. Especially this second dimension is one of the key issues in hub-network design literature. This number is either fixed (*p*-hub problems) or this number is variable and is determined by the network design model. The third dimension is single of multiple assignment (SA or MA) indicating the number of hubs a non-hub mode can be assigned to. This again is one of the key issues in literature on hub-network design.

Dimensions of hub-network design problem:

• Hub location	were to locate the hubs
• Number of hubs (fixed/variable)	number of hubs can be either fixed or variable
• Single/Multiple Assignment	assignment of the non-hub nodes to the hubs
• Continuous/Discrete space	solution space can be continuous or discrete
• Number of nodes	number of potential hub-locations
• Discrete/continuous demand	character of demand (accommodated by the network)
• Single/multiple commodity	the number of product categories
• Cost specification	can be flow dependent (hubs and inter-hub transfer)
• Hub network links	fully or not fully-connected
• Routing between hubs	hubs can be connected using sequences
• Hierarchy	different types of hubs can be distinguished

In addition to the dimensions mentioned above we distinguish continuous/discrete space, the number of potential nodes, demand, and multi-commodity. Another dimension that has received ample attention in hub-network design literature is the incorporation of flow dependent costs (see Table 2). Especially the incorporation of economies of scale on the inter-hub transfer and on the hubs themselves are important characteristics of a hub-network design model. In the next sub-section we will discuss different modeling approaches and elaborate on the different hub-network design dimension listed above.

5.4.1 Literature review on Hub Network Design

The two earliest reviews of hub location research are from 1994 by Campbell (1994) and O'Kelly and Miller (1994). Campbell provided a survey of the growing body of network hub location research and presented a classification scheme for the different models and problems considered. O'Kelly and Miller (1994) focused more on the topological alternatives available in hub networks. These two works summarized the early research on mathematical approaches to hub location problems, which began with the seminal work by O'Kelly for continuous (O'Kelly 1986a) and discrete location (O'Kelly 1987). Perhaps the earliest hub location model is in Goldman (1969) which extends the node optimality property of Hakimi (1964) to what is essentially the hub median problem. More recent reviews are provided by Klincewicz (1998) on the design of hub networks and the location of hub nodes in telecommunications, and Bryan and O'Kelly (1999) who surveyed work primarily in the context of air transportation and identified directions for future research. There is considerable literature on a variety of problems closely related to discrete hub location problems. This includes research on continuous space hub location problems, where the hub locations are allowed to be located anywhere in a continuous region (Aykin 1995b; Aykin and Brown 1992; O'Kelly 1986b; O'Kelly 1992a; O'Kelly and Miller 1991, Suzuki and Drezner 1997). One large area that is related to hub-network design is the research on designing hub networks, but without the hub location component. The relevant models generally are those with two or more model levels where the different levels form a hierarchy of hub-nodes (assigning volumes and calculating the routes of the flow). There is considerable literature on network design problems in which the location of the hub (backbone) nodes is specified (Klincewicz 1998). Another area of related research is multi-commodity network flows with concave costs (Minoux 1989).

In these problems the demand for each OD-relation is treated as a separate commodity and the flow cost along an arc is a non-decreasing concave function of flow on the arc. A final area of related research considers continuous demand many-to-many distribution problems with transshipment. In these networks, the demand is treated as a continuous density over a geographic region, and analytical expressions can be derived for the optimal location of hubs (transshipment facilities) and optimal average distance and costs. Models may include transportation, handling, inventory and facility costs. Campbell (1993) derives analytical solutions under the assumption that the demand is uniformly distributed and using rectilinear distances. Daganzo (1999) provides a summary of this literature, and provides analytical formulae to evaluate the benefits of one or more transshipments. We already presented the different dimension of the hub-network design problem. In the table below we present an overview of the available literature on hub-network design (we distinguish six of the key categories in hub-network design literature).

The early hub location models focused primarily on minimizing the flow cost and fixed facility costs for rather constrained situations where a single cost discount is used for all flows between the hubs. One important consequence of discounting all flows between hubs was that the optimal hub level network was a complete graph on the hubs. Thus, the design of the hub level network was determined by the location of the hub nodes. These models were extended by including features such as direct origin-destination flows not through the hub (Aykin 1994), capacities (Aykin 1994), and additional objectives, including mode choice (O'Kelly and Loa 1991) and congestion (O'Kelly 1986a).

Following the successes achieved and challenges identified in the first generation of hub location research, a second generation of research has produced substantial progress. This research sought to address some shortcomings of the early hub location models, as well as to solve larger problems of optimality. One approach to integrate network design and hub location was to consider a more complex and accurate hub level network. This includes models with flow-dependent cost discounts (Bryan and O'Kelly 1999; O'Kelly 1998; O'Kelly and Bryan 1998), models that relax the requirement that all flows between hubs are discounted, and models with minimum thresholds. Another approach to integrate network design and hub location was to consider a more complex and accurate access network. This includes models that allow direct origin-destination paths, so that not all flows go via a hub node (Aykin 1995a), multi-stop access paths (Klincewizc 1998), and collection and distribution routes. To address alternate levels of service, models have restricted paths to a specific number of hub stops or to a specific number of arcs (O'Kelly 1998a) Some research has also addressed scheduling issues (Kana and Tansel 1999b). Researchers have also sought to extend hub location models by considering additional costs. Transportation-oriented hub location research has focused mainly on flow costs, along with fixed costs for hubs when the number of hubs is not prescribed. Developing hub location models that include more of the relevant costs is important in producing more realistic and useful results. Finally, several new objectives are included. These works include minimizing the maximum costs or the latest arrival (Kara and Tansel 2000), hub covering models and hub location models with competition (Marianov *et al*. 1999).

Table 2: Analytical research on hub-network design.

Hub location research

Single Assignment	Multiple Assignment
O'Kelly 1987	Campbell 1994a
Klincewicz 1991	Ernst and Krisnamoorthy 1998
Abdinnour-Helm and Venkataramanan 1992	Klincewicz 1996
O'Kelly 1992b	Skorin-Kapov *et al.* 1996
Campbell 1996	Campbell 1994b
Ernst and Krisnamoorthy 1996	
Skorin-Kapov *et al.* 1996	
Aykin 1995b	
O'Kelly *et al.* 1996	
O'Kelly *et al.* 1995	
Smith *et al.* 1996	
Skorin-Kapov and Skorin-Kapov 1994	
Fixed number of hubs	**Variable number of hubs**
Grove and O'Kelly 1986	O'Kelly 1986a
Jeng 1987	Chou 1990
Flyn and Ratick 1988	O'Kelly 1992
Daskin and Panayotopoulos 1989	Campbell 1993
Hall 1989	Aykin 1994
Miller	Campbell 1994b
O'Kelly and Lao	Aykin 1995
Kuby and Gray 1993	Ernst and Krishnamoorthy 2001
	Jaillet *et al.* 1996
	Ebery et al. 1998
Flowdependent costs	**Exact solutions**
Bryan and O'Kelly 1998	Mayer and Wagner 2002
Bryan and O'Kelly 1999	Klincewicz 1996
O'Kelly and Bryan 1998	
Horner and O'Kelly 2001	

5.4.2 Taxonomy and models

O'Kelly and Miller (1994) presented a classification of hub network problems in which they organized the growing literature on the subject and provided a framework for standardizing the hub network design problem. A hub network consists of three major components: *nodes*, *hubs* and *arcs*. A service node is a point location from which flows can originate or into which destined for that location can enter. A hub has the characteristics of a service node but also allows the passage of through-flows or transshipment flows which are not destined for that location. The standard hub network (Type A) can be defined as the product of three simplifying restrictions: (1) all hubs are fully interconnected; (2) all nodes are connected to only one hub; and, (3) there are no direct non-hub to non-hub connections (Figure 5-9).

The Type A design has an important property and that is that the routing is deterministic. Given fixed hub locations, allocations of non-hub origins and destinations to hubs, and the triangle inequality with respect to distance, there is only one shortest path between any origin-destination pair in the network.

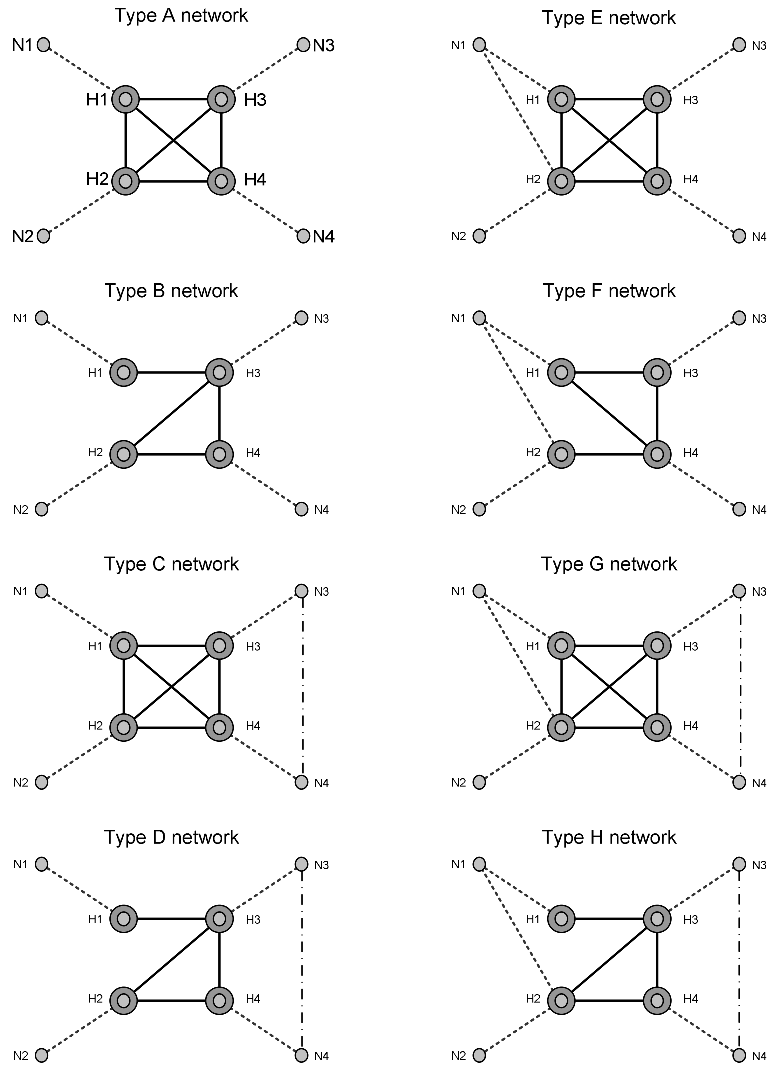

Figure 5-9: Overview of different types of hub-network layouts.
Source: O'Kelly and Miller, (1994).

Since each non-hub origin and destination is connected to only one hub and all hubs are interconnected, the triangular distance inequality means that the shortest path can be found simply by choosing the direct connections between a non-hub origin or destination and its hubs if necessary. This generic *hub and spoke* topology serves as the basis for the many-to-many distribution problem in a variety of empirical transport and communication applications.

However, the characteristics of these real-world distribution problems have resulted in hub network configurations that typically violate one or more of the Type A restrictions. One of the more common Type A relaxations attempted is the assignment of nodes to more than one hub. Multiple-hub assignment (MA) can save transportation costs by tailoring the selection of hubs to the eventual destinations of the flows being shipped from an origin node, thus reducing the distance traveled. As noted earlier, the Type A network is the product of three assumptions. Any of these rules can be relaxed providing three binary decisions variables with which to define hub network types. The three decisions are: (1) node assignment, either one hub or multiple, (2) direct node-node, either allowed or not, (3) hub inter-connection, either full or partial (Figure 5-9). In Figure 5-9 eight different hub-network types are presented based on three dimensions presented earlier; Single Allocation(SA)/Multiple Allocation (MA), fully or not fully connected hubs, and direct or no indirect service links. We presented this overview to illustrate the growing complexity when relaxing just three constraints (from SA to MA, allowing direct shipment, and not fully connected hubs).

5.4.3 The Objective

The hub network design problems that have received the most attention from researchers so far are the *p*-hub median problem, and the capacitated and uncapacitated hub location problem. We now present a basic mixed integer linear programming formulation for one of these problems. We will present a formulation for the uncapacitated multiple allocation *p*-hub median problem. The design variables are the location of the hubs (number is already determined), the assignment of non-hub nodes to one or more hubs, and the inter-hub flows. Before we present the formulation we provide the necessary notation.

Consider a complete graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ with a node set $\mathcal{V} = \{1,...,v,...,|\mathcal{V}|\}$ which is the node set of all origin and destination nodes. $\mathcal{E} = \mathcal{V}^2$ is the set of directed arcs and the set of potential hub nodes is $\mathcal{K} \subseteq \mathcal{E}$. The set of origin-destination pairs (OD) is $\mathcal{W} \subseteq \mathcal{V}^2$ and we consider a situation in which there are $\mathcal{I} = (1,...,i,...,|\mathcal{I}|)$ origins and $\mathcal{J}$ destinations indexed $\mathcal{J} = (1,...,i,...,|\mathcal{J}|)$. The volume on origin-destination pair (ij) is denoted d_{ij}. The distance between an origin and destination is denoted l_{ij}. The number of hubs to be located is denoted as *p*. Each origin and destination path can be viewed as consisting of three components: collection from an origin to the first hub, transfer between the first hub and the last hub, and distribution from the last hub to the destination. Paths involving only a single step are also possible and can be thought of as a special case in which the transfer is a null step. Parameters c_{ik}, c_s^{hub}, and c_{lj} reflect the unit costs for collection (origin-hub), transfer (inter-hub transfer), and distribution (hub-destination), respectively. Thus, the origin-destination path from non-hub origin *i* to non-hub destination *j* via hubs *k* and *l* ($i \to k \to l \to j$), incurs a cost $c_{ik}l_{ik} + \alpha_s c_s^{hub} l_{kl} + c_{lj}l_{lj}$ per unit flow. Generally α_s is used as a discount factor to provide reduced unit costs on arcs between hubs to reflect economies of scale, so $\alpha_s c_s^{hub} < c_{ik}$ and $\alpha_s c_s^{hub} < c_{lj}$. Thus the basic hub location model can be viewed as a two level network where the access level includes arc connecting non-hub origins and destinations to hubs, and the hub level includes transfers arcs connecting the hubs. Basic hub location models assume that every origin-destination path includes at least one hub node (i.e. all flows are routed via at least one hub), and the cost per unit is discounted between all hub pairs using α_s. The effect of this is that the access level network consists of single arcs connecting non-hubs to hubs, and the hub level network is a complete graph of the hubs (Type A in Figure 5-9). Basic hub location models have also focused primarily on the costs for flows in the network and for the fixed costs of hubs. The objective in the vast majority of hub location research is the minimization of costs, where the particular types of costs included depend on the application and context. Transportation-oriented hub location research focuses on flow-based transportation costs. Other objectives are, for example, objectives involving travel times, coverage measures, competition and congestion. To model the basic hub location problems we define three sets of decision variables corresponding to the three components of an origin-destination path, namely the collection and distribution components each involve a single access arc, which might be from a node to itself, if it is a hub.. Using the above variables this problem can be written as:

$$\text{Min } \sum_{i\in\mathcal{I}}\left[\sum_{k\in\mathcal{K}} c_{ik} l_{ik} Z_{ik} + \sum_{k\in\mathcal{K}}\sum_{l\in\mathcal{L}} \alpha_s c_s^{hub} l_{kl} Y_{ikl} + \sum_{l\in\mathcal{L}}\sum_{j\in J} c_{lj} l_{lj} X_{ilj}\right] \tag{5.20}$$

Subject to

$$\sum_{k\in\mathcal{K}} X_k = p \,, \tag{5.21}$$

$$\sum_{k\in\mathcal{K}} Z_{ik} = D_i \,, \qquad \forall i \in \mathcal{V} \tag{5.22}$$

$$\sum_{l\in\mathcal{L}} X_{ilj} = d_{ij} \,, \qquad \forall i, j \in V \tag{5.23}$$

$$Z_{ik} + \sum_{l\in\mathcal{L}} Y_{ilk} = \sum_{l\in\mathcal{L}} Y_{ikl} + \sum_{j\in\mathcal{J}} X_{ikj} \qquad \forall i,k \in \mathcal{V} \tag{5.24}$$

$$X_{ilj} \le d_{ij} X_l \,, \qquad \forall i,l,j \in \mathcal{V} \tag{5.25}$$

$$Z_{ik} \le D_i Y_k \,, \qquad \forall i,k \in \mathcal{V} \tag{5.26}$$

$$Z_{ik}, Y_{ikl}, X_{ilj} \ge 0 \,, \qquad \forall i,k,m,j \in \mathcal{V} \tag{5.27}$$

$$Y_k \in \{0,1\} \,, \qquad \forall k \in \mathcal{V} \tag{5.28}$$

where:

$$D_{i=} \sum_{j\in\mathcal{J}} d_{ij} \qquad \forall i \in \mathcal{V} \tag{5.29}$$

In the basic models the transfer component involves a single arc, though in more complex models the transfer component may involve several arcs. The decision variables are: Z_{ik} , the flow from origin *i* to hub *k*, Y_{ikl} flow between hub *k* and *l* that originates at origin *i*, and X_{ilj} flow between hub *l* and *j* originating at *i*. In addition to the decision variables for the flows on arcs, we have binary variables for locating hubs: $Y_k = 1$ if node k is a hub and 0 otherwise. The objective (5.20) sums the costs for collection, transfer, and distribution. Constraint (5.21) ensures that the appropriate number of hubs are selected. Constraint (5.22) ensures that all flows from each origin leaves the origin. Constraint (5.23) ensures that all flows for each origin-destination pair arrives at the proper destination. Constraint (5.24) is the flow conservation equation at the hubs. Constraints (5.25) and (5.26) ensure that hub nodes are established for every distribution and collection movement, respectively.

In the formulation above we presented a *p-Hub median formulation*; additional problem formulations can be found in Ernst and Krishnamoorthy 1999 and Klincewicz 1996. For example, *Hub-median problems*: in these problems the optimal number of hubs is determined as a part of the problem, usually by incorporating the fixed cost of establishing hubs in the objective along with other costs, such as flow costs. The objective captures the trade-off of increasing fixed costs from more hubs, with reduced flow costs from less circuitous routings (Ernst and Krishnamoorthy 1999; Klincewicz 1996; O'Kelly 1992b). O'Kelly *et al*. (1996) provide graphs showing the interaction between the fixed cost, the cost discount for inter-hub travel (α), and the number of hubs in the optimal solution. *Hub center problems*: the *p*-hub center problem is to locate *p* hubs to minimize the maximum distance or cost between any pair of nodes. The single allocation variant (SA) of this problem has been considered by Kara and Tansal (2000). *Fixed costs on arcs*: fixed costs for arcs are important in many applications, where the cost of establishing arcs is high compared to the cost of operating them. Note that arcs may represent links that are privately owned, such as telecommunications networks or railways, or publicly owned, such as airways in a transportation network. *Flow (transportation) costs*: some models adopt flow cost functions that are concave to reflect economies of scale; the cost per unit flow decreases as the flow increases (Bryan 1998; O'Kelly and Bryan 1998; 2002). In particular these authors consider a piecewise linear, concave cost function for the flows between hubs. Note that this is equivalent to considering multiple possible discount factors alpha, but with corresponding fixed costs which increase for greater discounts.

5.4.4 Solution approaches in hub network design

In general three approaches are proposed to handle the mathematical complexity of hub network design problems. The first approach is to adopt a partial approach, whereby some aspects are simplified for mathematical convenience. The second is to find a way to separate the problem into convenient sub problems. Finally, the third approach is to recognize the inherent mathematical difficulty, and to seek a local rather than a global optimum (O'Kelly and Miller 1994; Current *et al*. 2002). The limited work that has been done on analyzing the complexity of hub location problems has mostly focused on the *p*-hub median (SA) problem. The hub-problem is known to be NP-Hard. In fact, even for a given set of hubs, the assignment problem of optimally allocating the non-hub nodes is already NP-Hard. Another example is the hub-center problem (SA) which is also NP-Complete. Again it can be shown that even the allocation part of the problem for a given set of hubs is NP-Complete. The multiple allocation problems for fixed hubs, on the other hand, can be solved in polynomial time using an all-pairs shortest path algorithm provided the hubs are un-capacitated (Ernst and Krishnamoorthy 1998a; Sohn and Park 1997).

One useful technique for improving the efficiency of solving the problems in practice, as with many combinatorial optimization problems, is pre-processing of the problem data, though it does not change the theoretical complexity of the algorithms. The most common approach to solving hub-network design problems is using linear programming. The formulations used fall into two broad categories. The first uses $\mathcal{O}\left(n^4\right)$ variables in order to track the flow between every origin destination pair (e.g. the formulation for the un-capacitated multiple allocation hub location problem given in (5.20). This type of formulation is very tight but also very large as it not only has a large number of variables but also requires $\mathcal{O}\left(n^3\right)$ constraints. The fact that both the number of rows and the number of columns increases rapidly with problem size means that these formulations are not amenable to branch-and-price or branch-and-cut techniques. Hence it is very difficult to solve the LP relaxation for problems involving more than 25 nodes. However these types of formulations still provide a good starting point for algorithms using dual ascent or lagrangean relaxation since they are quite tight. For a given set of potential hub locations the number of integer variables in multiple allocation (MA) is relatively small. This problem, therefore, can be solved very quickly; the number of hubs is provided and the number of potential hub locations is known. The use of *enumerative algorithms* as a reasonable approach for solving this type of hub-network design problems has been suggested by Aykin 1995 and Ernst and Krishnamoorthy 1998a.

For example, making use of a shortest path algorithm for the allocation problem by enumerating all possible hub locations for a problem such as the multiple allocation p-hub median problem is one way of using this approach. While this algorithm is exponential in *p*, it is polynomial in *n* and for most problem instances the number of hubs is comparatively small. As each hub combination can be evaluated very quickly, this gives a viable solution approach for multiple allocation problems, provided the number of hubs to be enumerated is comparatively small (Ernst and Krishnamoorthy 1998b).

Heuristic approaches

Due to their mathematical complexity hub location problems are difficult to solve exactly. The best methods available so far cannot solve instances with more than 50 nodes unless the number of potential hubs is significantly restricted. This has led to a proliferation of heuristics to tackle the many types of hub-network design problems proposed in the literature for various applications. The large number of different heuristic methods used is not only due to the variety of problem variants, but also an indication that there are many different approaches that can be used to produce satisfactory solutions to hub location problems. Klincewicz (1991) presents a number of heuristics based on local neighborhood search and the clustering of nodes and also developed a tabu search and GRASP heuristic (Klincewizc 1992). Another tabu search algorithm for this problem which performs better has been developed by Skorin-Kapov and Skorin-Kapov (1994). Yet another approach is to use simulated annealing (Ernst and Krishnamoorthy 1996). An interesting use of the heuristic solutions is given by O'Kelly *et al*. (1995), who use the reference solution to generate lower bounds that can give an estimate of the quality of the solution. Abdinnour-Helm (1998) uses a hybrid heuristic combining genetic algorithms and tabu search to obtain good solutions to the un-capacitated single allocation hub-network design problem.[8]

[8] See for additional information on the heuristic simulated annealing, discussed in this chapter, see Appendix C:Solution procedure SA where this technique and the performance on hub network design is discussed.

Capacity Restrictions

In the literature on hub network design several types of capacity restrictions have been introduced: (1) capacity constraints on the nodes, (2) on the arcs, and (3), performance constraints. In much of the literature the constraint of using exactly p-hub nodes is dropped when capacities are imposed on the hubs, so that the optimal number of hubs is determined endogenously by the model as part of the optimization. Aykin (1994) restricts the number of hubs to be exactly p, while imposing capacities on throughput and considering fixed costs on the hubs. Another constraint is a capacity restriction on the arcs, proposed by Bryan (1998), who explores the relationship between capacities and the piecewise linear cost function for inter-hub arcs for a given set of hub nodes. Aykin (1996) was one of first to suggest the use of minimum flow thresholds to improve the basic hub location problems in this regard. Aykin suggests various types of thresholds based on the amount of flow going through a hub or the inter-flows. Flows on arcs in the access network also might have unrealistically low volumes, especially in multiple allocation problems. Bryan (1998) proposes a thresholding scheme where inter-hub arcs carrying less than the minimum amount of flow are simply not allowed. One method is to modify the multiple allocation *p*-hub median problem by dropping the assumption that all pairs of hub nodes are directly connected. Alternatively, flow thresholds can be used to determine the number of hubs. A more detailed discussion of a particular thresholding scheme where the per-unit cost of flow across an arc is either discounted or incurs the full cost depending on whether the flow across the arc exceeds some given threshold or not.

A variety of constraints may be included in hub location models to ensure that the hub network can effectively handle the traffic. These constraints are most common in telecommunications based research and may be of various forms, including limits in the percentage of calls blocked due to insufficient capacity, limits on the transmission time or limits on queue lengths or delays. See Klincewicz (1998) for details.

5.4.5 Discussion

In this section we discussed the state of the art on hub network design models and the different approaches reported in literature. We discussed the key activities in the logistics network that we need to take into account when designing hub-networks concerning motion (collection, transfer, distribution), holding, handling and administrating.

Although use of indirect (that is via a hub) shipment may increase the distances traveled, the economies of scale due to the larger volume can reduce the total cost. It is of critical importance, when designing these networks that capacity restrictions and service criteria are taken into account (frequency, shipment size, and lead-time). We presented the different types of hub-networks, based on O'Kelly and Miller (1994) using three assumptions: (1) node assignment, either one hub or multiple, (2) direct node-node, either allowed or not, (3) hub inter-connection, either full or partial (Figure 5-9). Out network design problem deals with a Type H hub-network relaxing not only the three mentioned constraints but also introduce routing between the hubs and capacity restrictions on the hubs. In the next section we present an example that is based on realistic order information and was designed using our hub-network design algorithm that will be discussed in detail in Chapter 7.

5.5 An example of a hub network design problem

To illustrate a hub-network design application we present an example of a realistic European hub-network. Based on the flows between approximately 700 locations (production, warehouse, wholesalers, dealers, and customers) we designed an FTL hub-network. The customers are primarily located in the larger cities in Western Europe. These flows consist of apparel, consumer electronics, printers, faxes, parts, and components.

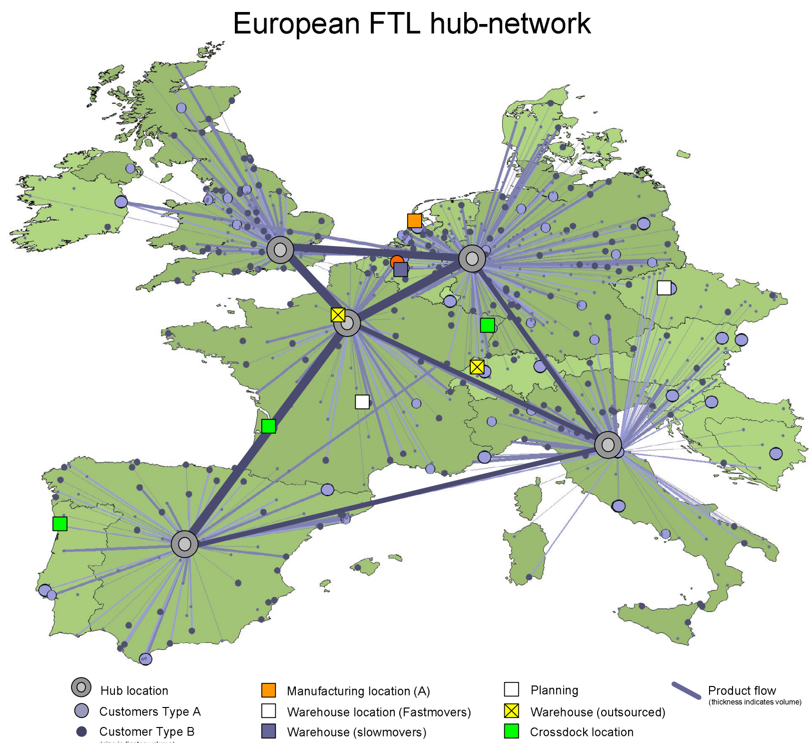

Figure 5-10: Example of a dedicated European FTL hub network (Groothedde 2002).

The total flow between these origins and destinations is 1,578,000 shipments/year and a calculated average of €78.40/shipment. The shipment sizes range from 0.10 m3 to 1.5 m3 and the total calculated costs are €123,000,000 annually. The objective of the algorithm is to minimize the total costs (motion, waiting, and handling). The decision-variables in this example are the number and location of the hubs, the inter-hub services, and direct or hub-shipment (in total 50 potential hub locations are used). An important constraint in this specific example was the 48-hour lead-time. From each origin every customer needs to be reached within a 48-hour lead-time, including the collection, trans-shipment at the hubs, inter-hub transfer, and distribution. Based on the customer demand, the locations of the originating nodes (manufacturers, dealers, and wholesalers), shipment costs in the starting situation, and the potential hub-locations, the resulting hub-network presented in Figure 5-10 was designed. The network design problem was solved using our Simulated Annealing Heuristic. This solution methodology will be discussed at length in Chapter 7.The total logistics costs of this network solution are €98,000,000/year, yielding a cost reduction of €25,000,000/year, a 20% cost reduction. The fraction of the shipments that is accommodated by the hub-network is 78% of the total of 1,578,000. In total 5 hubs resulted (Madrid, Paris, London, Düsseldorf, and Bologna), with 16 inter-hub services, of which 14 services directly connect 2 hubs, and 2 services make an intermediate stop (Madrid $\rightarrow$ Paris $\rightarrow$ Düsseldorf and Düsseldorf $\rightarrow$ Paris $\rightarrow$ Madrid). We did not use any routing algorithm for the collection and distribution leg so it is assumed that direct transport is used for the shipment from the origin to the hub, using an average shipment-rate. It can be argued that additional cost reduction can be achieved when a routing algorithm would be used to optimize the collection and distribution (the average shipment rate is very conservative and leaves room for improvement).

5.6 The need for innovation

In this chapter we discussed the importance of accurate cost calculation and presented three approaches reported in the literature. In section 5.2 the cardinal trade-offs of this dissertation were discussed followed by the state-of-the-art on hub-network design (sections 5.3 and 5.4). We have seen that a hub-network is particularly suited for combining and consolidating the flows of different shippers and hereby achieves economies of scale. When using standardized loading units, the handling, sorting, and transshipment activities can be standardized and the investment can be kept economical. Consolidation in these types of networks allow more efficient and more frequent shipping by concentrating large flows onto relatively few links between hubs. Although use of indirect (that is via a hub) shipment may increase the distances traveled, the economies of scale due to the larger volume can reduce the total cost. These configurations can reduce and simplify network construction costs, centralize commodity handling and sorting and allow carriers to take advantage of economies of scale. Consequently, we have seen numerous initiatives for hub-networks in which the flows of different shippers are consolidated. However, when the actors need to work together and take part in a collaborative hub-network, additional contingencies are introduced, leading to added complexity and constraints in the network design problem we are trying to solve. The myriad of relations and interactions between the actors operating in these networks poses structurally complex network design problems for each of the organizations individually and for the network as a whole. Whereas contractual relationships are one-to-one by definition, the network design problem is a many-to-many problem. Apart from questions concerning the locations and number of production sites and warehouses, tactical and operational issues of stock positions, mode choice and delivery frequency have to be addressed. In many organizations, however, the different logistics sub-functions are controlled and optimized independently; in theory, modeling and practice. In our framework we strive to include an integral cost trade-off addressing these aspects.

Thus far, the design of a logistics network in which the different actors collaborate in order to decrease costs or increase the service level is an issue that has received little attention in the literature. This is in contrast to the attention that organizational issues of partnerships, alliances and supply chain management have received in recent years. Camarinha-Matos and Afsarmanesh (2004) state: *"After an initial phase in which in spite of the considerable investments in collaborative networks, most of the approaches were highly fragmented and case-based, it is now urgent to* *consolidate and synthesize the existing knowledge, setting a sound basis for the future. One of the main weaknesses in the area is the lack of appropriate theories, consistent paradigms and formal modeling tools".* In the sequel of this dissertation we focus primarily on the design of logistics networks in which the actors collaborate and make a substantial extension to the existing hub-network design models (including transaction costs, service on the inter-hub transfer, capacity restrictions, and delineating the development path).

As we discussed in this chapter, considerable progress has been made with optimization techniques, algorithms and the available technology needed to solve these complex design problems and as algorithmic tools evolve, so do the complexity and realism of the problems that can be tackled. However, while finding an optimal solution is one thing, the path towards this network solution, derived using these sophisticated tools, is as important as ever, although this development path has received very little attention. As most companies' starting situation is not a so-called Greenfield, we explicitly will focus on this development path and incorporate the capability to include constraints and requirements on the development path. Instead of solely minimizing the total costs in the logistics network or minimizing the costs of individual companies, we will, when designing a collaborative network, take into account the scope of the collaboration and the type of partnership, and tabulate the implications the type and scope of the collaboration have on the costs for the individual participant. The type of network design problem we will address in our design framework in the next chapters is a hub-network in which the actors collaborate, they can choose between direct and indirect transfer, the hubs are not necessarily fully-interconnected and capacity constraints are placed on both the hubs and the inter-hub connections.

6 A framework for designing collaborative networks

Decisions related to the design of a hub network are among the most critical in logistics management decisions. Both the costs of a distribution system and the quality of customer service that can be provided by the system are significantly affected by the design elements mentioned in the previous chapter (number of hubs, their location, customer assignment, capacity, inter-hub services, etc.). Consequently, a great deal of effort has been devoted to the development of mathematical models to support decisions related to the design of logistics and hub networks in which significant progress has been made in the last decades. However, the existing mathematical models still focus primarily on individual components of the design problem, particularly on the location of facilities, whilst ignoring or making some restrictive assumptions regarding the alignment of the network, the scheduling or resource deployment.

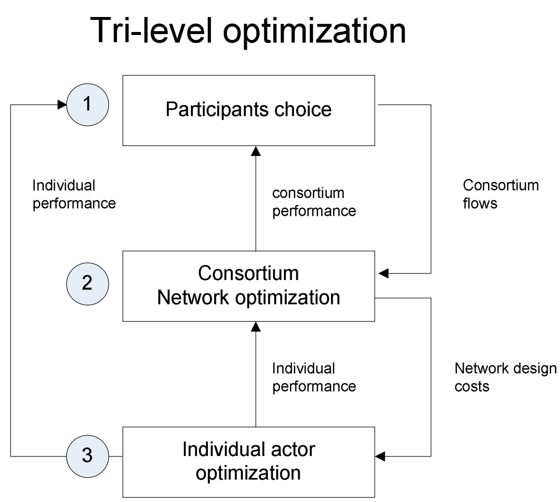

Figure 6-1: the different levels of the optimization problem.

In search of a feasible network solution in which the participants collaborate we will incorporate important issues in the alignment of the network (e.g. inventory deployment), scheduling of the network (service network design), and resource deployment (routing of means of transport). Optimization of the supply chain, or logistics network, has been well documented in the literature, as the vast literature on optimizing the business processes of individual companies indicates. In this chapter we develop a framework for a modeling approach to design a logistics network in which the participants collaborate. In section 5.5 we presented a basic hub-network design problem and a network solution derived using a standard hub-network solution algorithm. The introduction of collaboration in these types of networks results in a tri-level optimization problem in which the consortium of participants take decisions on the admittance of new participants and on the development path, introducing additional complexity into the design problem (see Figure 6-1). Three steps are distinguished: (1) the participant's choice, the consortium network optimization, and (3) the individual actor optimization. The choice of the participant (1) is based on the performance of the consortium (costs and service) and the performance the individual actor can obtain when optimizing its own logistics. The choice of the participants determines the consortium flows and thus the optimization of the network by the consortium (2). Finally the costs when participating in the network determines the optimization of the individual actor (3).

Instead of minimizing the total costs in the logistics network, or minimizing the costs of individual companies, we try to minimize the costs within the collaboration, given the reluctance companies have to switch from one network solution to another. In this approach we make use of *Transaction Costs Economics* to model the resistance organizations have to participating in such partnerships, as discussed in Chapter 3. Next we will present a typology of collaboration in which we will focus on several key characteristics of collaboration that we will use to systematically describe several illustrative examples of collaboration (section 6.4). In section 6.5 we present a stepwise approach to design collaborative networks and to evaluate their performance.

6.1 Modeling collaboration in logistics networks design

Logistics network design is highly complex, especially if performed for more than a single firm or actor which in today's business environment is almost always the case. Everybody seems to be convinced of the fact that supply chain management is of great importance, however no efforts have been made to include this in the optimization of the network. To design a logistics network, models are more and more capable of dealing with this complexity and integrative approaches incorporate more variables and complexity, making it possible to model the behavior of multiple actors and design a network based on the requirements set by these actors.

6.1.1 System optimization

Designing a collaborative network is an even more complex undertaking which differs from *simply* optimizing a logistics network in the sense that more criteria have to be met during the search for the optimal solution for an enlarged group of participant. The objective is to optimize not only the performance of the overall network from the perspective of the current participants[9], but in addition, searching for the optimal solution for the individual potential participants. In Figure 6-2 an example is presented of the result of a hub network design

[9] The participants who currently participate will be referred to as the consortium and can introduce additional criteria that have to be met during the further development of the collaborative network (see section 6.1.3).

model. In this figure four focal firms are illustrated, including their boundaries.[10] These four firms are the potential participants of the collaboration, using a hub network for their transportation between the different locations in the network. The solid lines denote institutional links, (including deliveries), the dotted-lines denote deliveries, and the dotted lines connecting the hubs denote inter-hub transfer services. For all four companies the efficient boundaries are depicted. The other firms, depicted with the notation presented in section 3.2, are outside the scope of the collaboration.

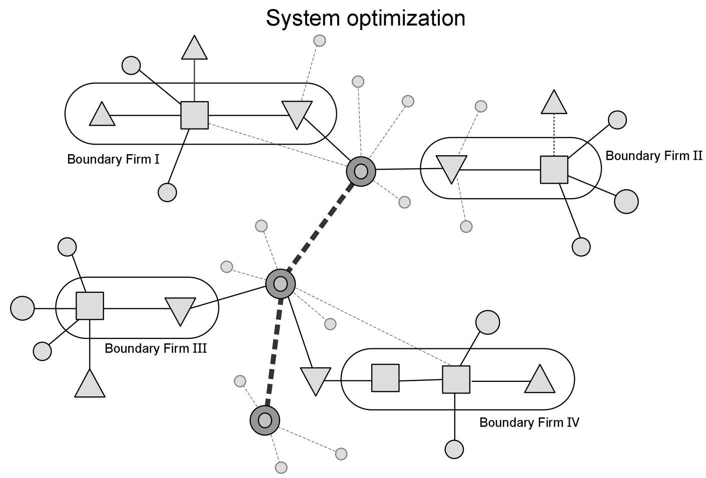

Figure 6-2: Resulting hub network using system optimization only.

Using an optimization model that for example minimizes the system-wide costs, a network solution, presented in Figure 6-2 could well be the result. This network solution consists of a 3-hub network connecting all participants and other firms with one another. In this example the optimum is sought using all available flows and trying to minimize the costs (system-wide costs). It could well be in this example that for a specific manufacturer-customer relation joining the network would not be beneficial.

However, in these types of networks, the economies of scale that can be achieved by consolidating all flows, can make up some of the loss of individual participants, yielding an overall cost reduction. If however the costs were minimized for the individual participants, the probability of a hub network appearing in the network solution is minimal due to the high operating costs and the lack of scale that each participant, individually, can bring to bear. A possible network solution that could well be the result of such a model is presented in Figure 6-3. In this solution again the four focal firms with their links with each other and other firms are depicted (solid lines). Next to the relationships with other firms the interaction in terms of product flows are depicted (dotted lines). Clearly, a more fragmented pattern of interacting flows is the result of the optimization. As we have seen in Chapter 3 firms are reluctant to

[10] Note that in this representation a combination is made between the functional boundary of the firm and physical network locations of, for example, a hub network. This, debatable combination, is made for illustrative purposes only and depicts the choice a firm makes individually (the boundary of the firm) and the network solution (hub network design).

participate in any collaboration or switch from one network alternative to another due to all sorts of contingencies and barriers. Williamson (1991):"*Vertical and lateral integration are usually thought of as organization forms of last resort to be employed when all else fails. That is because markets are a marvel in adaptation respects."* Due to governance costs, trust issues and transaction costs the firms are usually reluctant to make the switch. The individual firms make this assessment individually and if the transaction costs weigh up to the benefits of either outsourcing or collaboration they will make the switch. If this is not efficient the firms decide to seek an in-house solution.

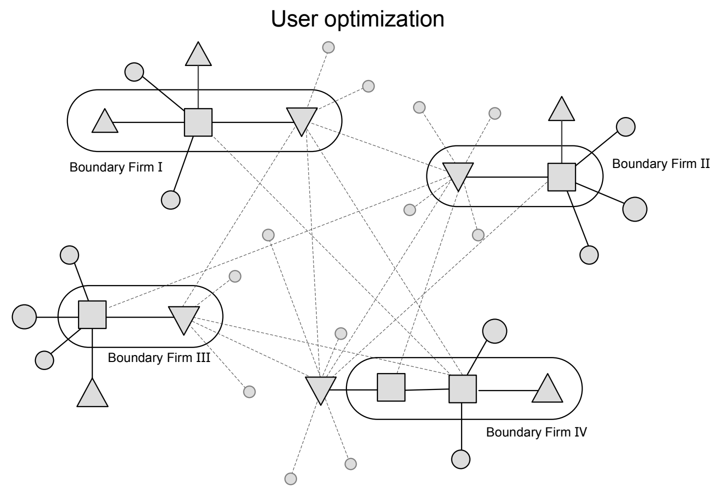

Figure 6-3: Resulting hub network using user optimization only.

6.1.2 Optimization of the consortium

Thus we have to find a way in which the individual trade-off of the potential participants is incorporated, based on their transaction, governance and switching costs, and, in addition, on the influence the type of collaboration has on these variables. For example, a long term, structural collaboration with shared risks and low asset specificity will result in lower transaction costs and resistance than a short-term, uncertain initiative with a high level of asset specificity. Next to the requirements set by the potential participants it is important to take the objectives of the consortium into account, for it is important to these participants that new members join so that the costs of the consortium decrease. The challenge is therefore, to model collaboration and design collaborative networks: (1) to minimize the sum of all individual costs of all potential participants, and (2) take into account the resistance of individual firms to participate, and (3) take into account the potential resistance of members of the consortium to let new members enter the consortium. In other words the design variables are the capacity of the hubs, the inter-hub services, and direct or hub shipment; not only the total network costs need to be minimized but the costs of the participants in the consortium need to be minimized as well (logistics and transaction costs). In addition we introduce the decision to participate in the consortium as a design variable. Next to these design variables transaction costs and resistance to participate is introduced.

In our example, with the four focal firms, we introduce the transaction costs (δ^{tc}) and the additional resistance there might be to participate due to dominance, transparency and uncertainty issues, summarized in the variable ϵ^{s} of all the individual potential participants. Based on the type of collaboration the impact on the transaction δ^{tc} and ϵ^{s} is computed and the decision-making process of all potential participants is modeled. During the development of these types of networks the behavior of the participants in the consortium and potential participants is of great importance to potential partners.

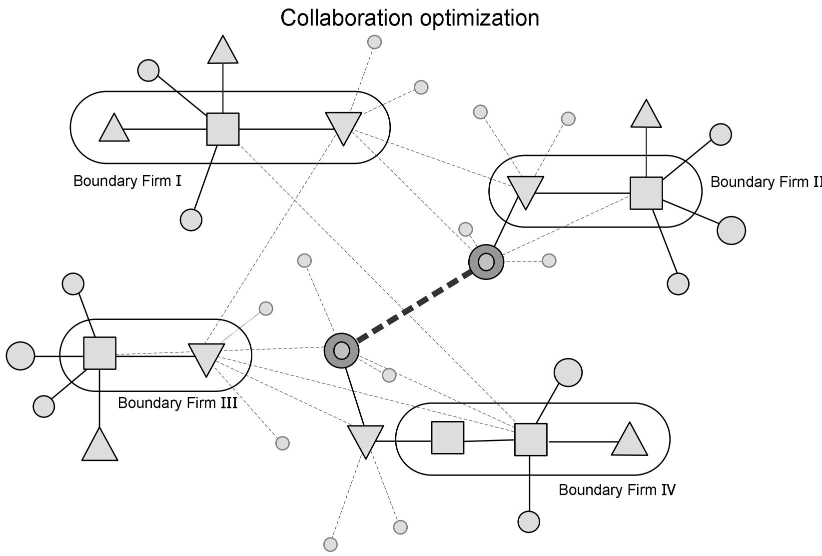

Figure 6-4: Resulting network after optimizing the collaboration.

The use of the network or size of the consortium already present influences the individual decisions to participate. For every developmental step of the hub network the consequences for the transaction costs, cost for the participants, and consortium costs need to be recalculated and the influence on the decision to participate needs to be modeled. If we then try to optimize the collaborative hub network, a possible network solution as depicted in Figure 6-4 could well be the result. In this example the procedure yields a network with two hubs, primarily connecting Firm II and Firm IV with each other. The trade-off between the transaction costs and the potential benefits gained by participating is negative for Firm I and Firm II in this example. We have already mentioned that the potential participants are reluctant to switch to the collaboration due to the factors mentioned earlier. In section 6.1.3 we will address this issue in more detail. The results presented in Figure 6-2, Figure 6-3, and Figure 6-4 illustrate the outcomes of a methodology capable of optimizing collaborative networks which in essence searches for a second best feasible network solution. The optimal network solution is usually not feasible or very difficult to implement. The user optimum methodology results in fragmented flows, because none of the individual firms can bring about the scale needed to exploit a hub network efficiently nor is willing to invest in such a hub network due to the risk involved, and it not being their core business. But there are certainly possibilities for consolidating flows and achieving economies of scale when collaborating.

6.1.3 The hybrid approach for network optimization

In the previous section we discussed the search for the so-called *second best* solution; trying to find a network solution that is accepted by the potential participants and the consortium. This approach is referred to as the *hybrid approach* to network optimization. In addition, not only the final network solution but the path towards this final solution is important. For potential participants one of the key uncertainties is the development of a network; how do we get from *ist* to *soll*.

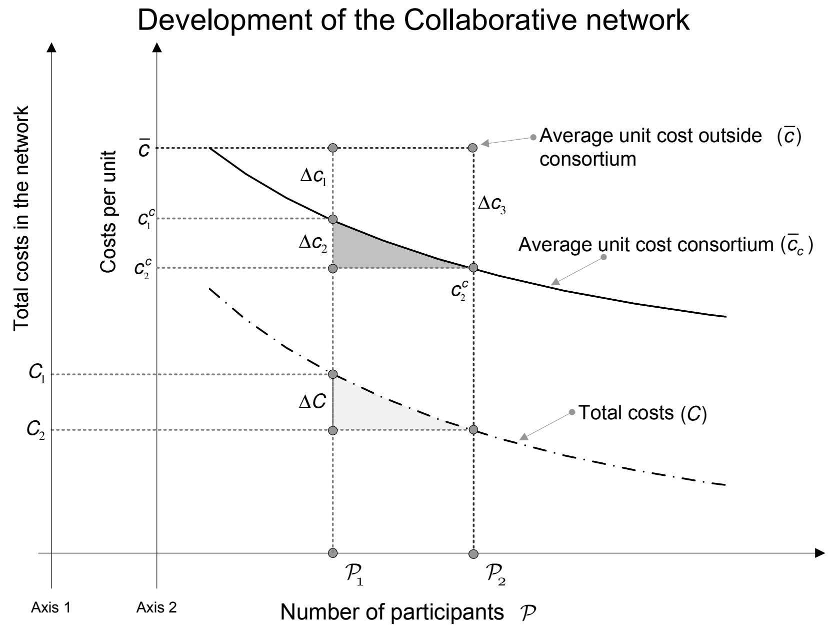

Figure 6-5: Illustration of the development of a collaborative hub network

In Figure 6-5 an example is presented in which a possible development path is illustrated. On the horizontal axis the number of participants is depicted ($\mathcal{P}$). There are two vertical axis included in the figure. Axis 1 indicates the total costs (C) in the entire network of all participants and potential participants (in and outside the consortium). Axis 2 denotes the costs per unit for all (potential) participants. There are two curves included in the figure, the average unit costs of the members of the consortium (continuous line), denoted $\bar{c}$, and the total costs (dashed-dotted line). In this example the average unit cost ($\bar{c}$) outside consortium is assumed constant. The development of the network is proportional to the number of participants $\mathcal{P}$ in this example. So let $\mathcal{P}_1$ denote a certain stage in the development of the network with an average cost per unit for consortium members of c_1^c and a total costs level of C_1. These members of the consortium $\mathcal{P}_1$, realized a cost reduction of $\Delta c_1 = \bar{c} - c_1^c$ compared to no consortium. A possible step in the development could result in $\mathcal{P}_2$ members of the consortium yielding an additional total cost reduction of $\Delta C = (C_2 - C_1)$ and a further reduction of the average unit cost of Δc_2.

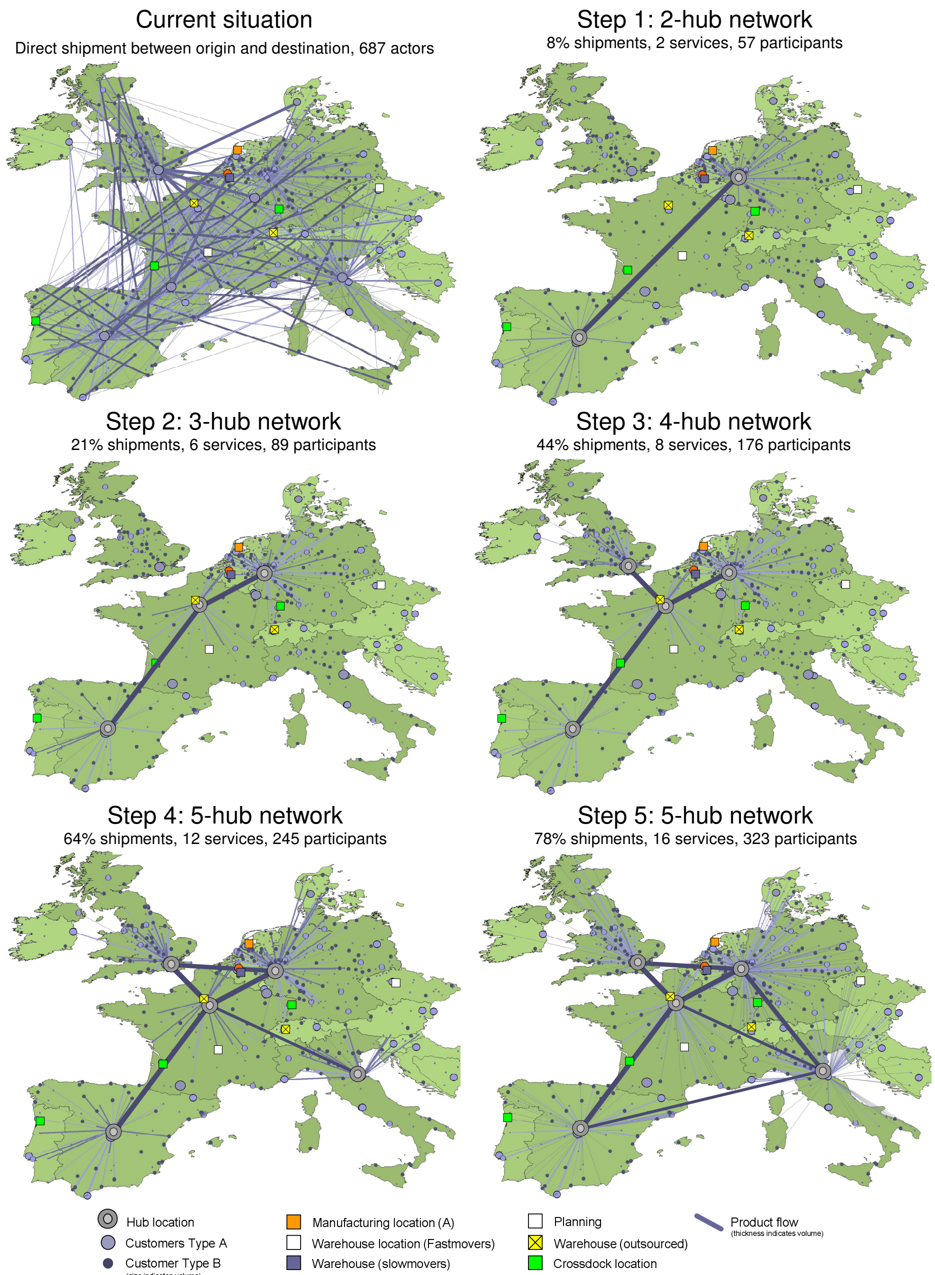

Figure 6-6: Development of an European Hub-network.

However, for the members $\mathcal{P}_1$, already in the consortium, this would result in a further cost reduction of Δc_2 in contrast to the reduction of Δc_3 for the new participants. The question is if this is acceptable for the members $\mathcal{P}_2$ of the consortium, or that additional demands will be introduced, resulting in some sort of threshold, minimum cost decrease or compensation distributing this ΔC. These gain sharing issues are very important in these kinds of collaborations (Vos *et al.* 2002). In our example it could well be that the Δc_2 is found insufficient in the eyes of the consortium members and they demand some of the benefits of the Δc_3 reduction of the new participants. Finding the optimal way to distribute these benefits is outside the scope of this research.[11]

To illustrate this development of the network an example is presented in Figure 6-6. The potential participants are in total 687 individual shippers (manufactures, wholesalers, and retailers) located throughout Europe. The total potential hub locations is again 50. In this figure the starting network and five steps of the development path of this network are depicted. We presented the final network solution (step 5 in Figure 6-6) in section 5.5 to illustrate a standard hub-network design problem and solution. Based on the flows between approximately 700 locations (production, warehouse, wholesalers, dealers, and customers) a FTL hub-network was designed, but in addition we also depict the development path towards this final network solution. Again, the total flow between these origins and destinations is 1,578,000 shipments/year and a calculated average of €78.40/shipment. The shipment sizes range from 0.10 m3 to 1.5 m3 and the annual calculated total costs are €123,000,000 annually. The starting network consists of solely direct shipments between the origins and destinations, then, using the hub-network design algorithm the first step in the development is derived and illustrated in Figure 6-6: *Step 1: 2-hub network*.

This first step consists of 2 hubs, one in Madrid and one in Düsseldorf, with 2 services connecting both hubs (Madrid → Düsseldorf and Düsseldorf → Madrid) and 8% of all shipments sent though this network. Note that for illustrative purposes only the shipments sent through the hub-network are depicted. The second step in the development of the hub-network is a 3-hub network, accommodating 21% of the shipments with 6 services. This third hub is located in Paris. The third step consists of a 4-hub system with 12 services and a fourth hub, located in London. In total 48% of all shipments is accommodated by this network solution and the 12 services. In this network there are six services that connect two hubs, for example London → Paris and Düsseldorf. In addition there are 6 services that link two hubs, but include an intermediate stop, for example, Düsseldorf → Madrid, with an intermediate stop in Paris. The fourth step in the development is a 5-hub network, connecting Paris, London, Madrid, Düsseldorf, and Bologna. In total there are 16 services connecting these five hubs and based on the shipment costs it is cost-efficient for 78% of the shipments to be sent through the hub-network.

For the remaining 22% it is cost-efficient to ship directly between origin and destination. The total logistics costs of this network solution are €98,000,000/year, yielding a cost reduction of €25,000,000/year, a 20% cost reduction. Using our framework makes it possible to delineate the development path of the network, as illustrated in Figure 6-6.

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[11] For additional information concerning these issues we refer to Vos *et al.* 2002); Cruijssen *et al.* (2004) in which different strategies to share these gains are evaluated.

In addition it is possible to calculate the individual benefits of all current and potential participants. This in turn makes it possible to derive the added value of the individual participants, and the added value the potential participant might have when they decide to join the network. In Figure 6-7 the next development step of the network is illustrated. This figure corresponds with *Step 2: 3-hub network* illustrated in Figure 6-6.

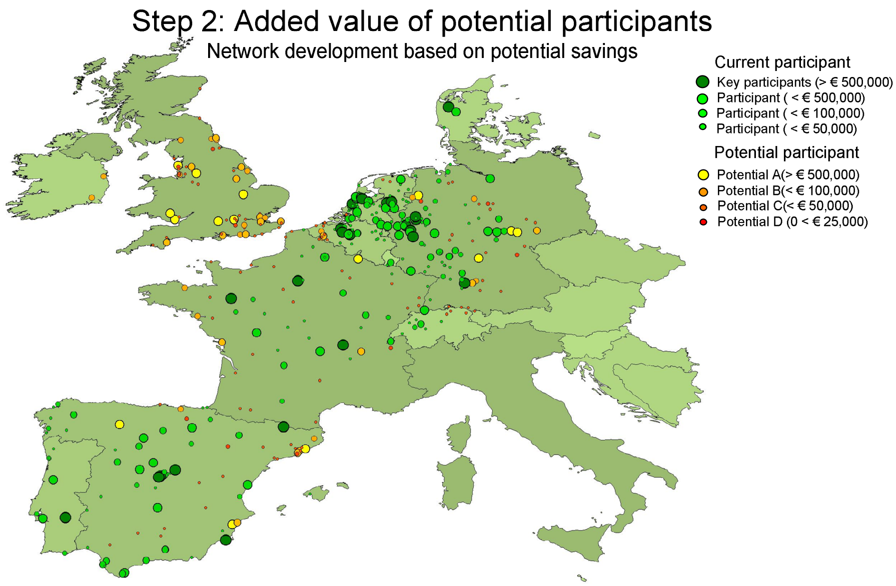

Figure 6-7: added value of current and potential participants..

This network consists of three hubs. The fourth hub is to be located in London (*Step 3: 4-hub network* in Figure 6-6). The potential added value of primarily user in the vicinity of London is thus depicted. The ability to identify the participants and important potential ones at an early stage enables the consortium or service provider contracted by the consortium to focus on the key contributors and minimize the search costs component of the transaction costs.

6.2 Logistics service versus the costs

In the previous section we presented an example of a hub-network that was derived using our design methodology. The costs in this network were based on the integral logistics costs consisting of costs incurred for the operations mentioned in Chapter 5. These operations include costs related to motion, holding, overcoming time, and handling. In the starting situation the total flow between the included origins and destinations was 1,578,000 shipments/year and a calculated average of €78.40/shipment.

The total integral logistics costs calculated were €123,000,000 annually. The total logistics costs of the newly designed hub network solution were €98,000,000/year, yielding a cost reduction of €25,000,000/year, a 20% cost reduction. The fraction of the shipments that is accommodated by the hub-network is 78% of the total of 1,578,000. However, this performance in costs can only be assessed when taking into account the performance of network in terms of customer service. An important attribute of any logistics network solution is the responsiveness of the network in terms of lead-time. What is the time between the placement of the order and making the actual delivery? We refer to this as the proximity of the customers (closely related to the *space accessibility* we discussed in section 2.3). In Figure 6-8 we present an example of the customer cover in terms of the proximity of the customer to the nearest hub (Groothedde 2002). The contours in this overview denote the shipment time from the hub to the customers, based on the physical network characteristics.

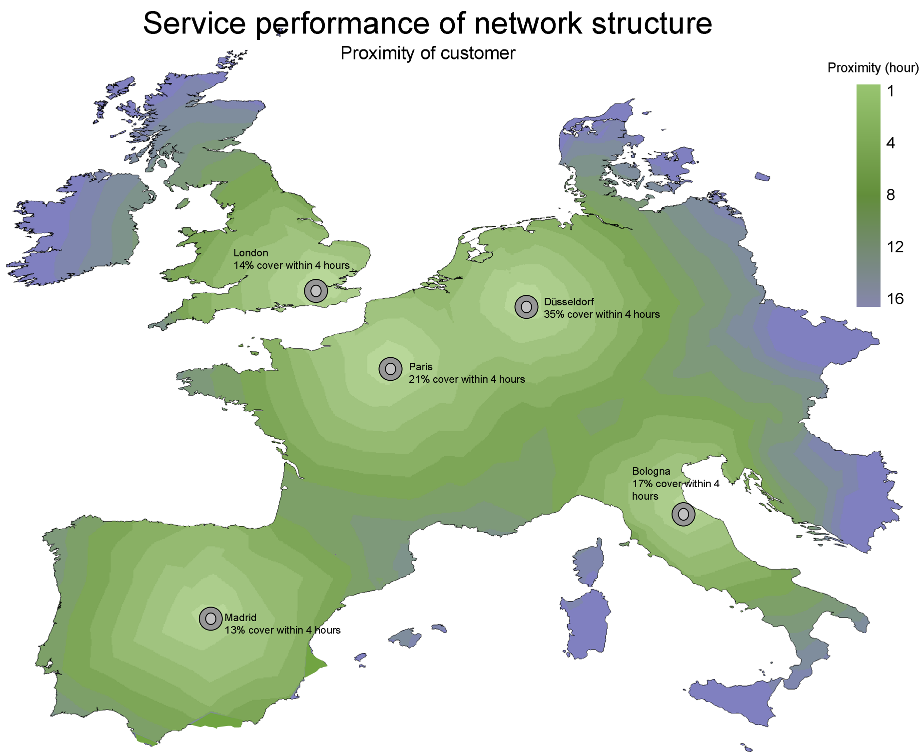

Figure 6-8: Logistics service: customer proximity of the hub network solution (5-hub network).

In the example presented in Figure 6-8 the proximity of the customer from the point of view of the nearest hub is illustrated. The shipment times from the hub to the customers are calculated based on the network European road network infrastructure (not depicted in the figure). Then, using the colors indicated in the legend (ranging from light-green to dark blue) the shipment time is depicted using the colored contours.

For example, the hub in Düsseldorf covers 35% of all customers of the hub network within a 4-hour lead-time; the hub in Paris covers 21% of the customers within this same lead-time. The hub located in Bologna covers 17%, the hub in Madrid covers 13%, and finally the hub located in London covers 14% of the customers within a 4-hour lead-time. Note that there can be an overlap in customer cover (e.g. the percentage depicted in Figure 6-8 can exceed 100%). The performance of the presented hub network design (*Step 5: 5-hub network* in Figure 6-6) with the hubs presented in Figure 6-8 above accommodates 78% of all shipments, using 16 services and is used by 323 participants. The customer cover is 61% of the 323 participants (e.g. 197 participants) within the 4-hour lead-time. Note that this 4-hour lead-time is not the total shipment time through the hub-network. The collection and inter-hub transfer are not included in the mentioned 4-hour lead-time.

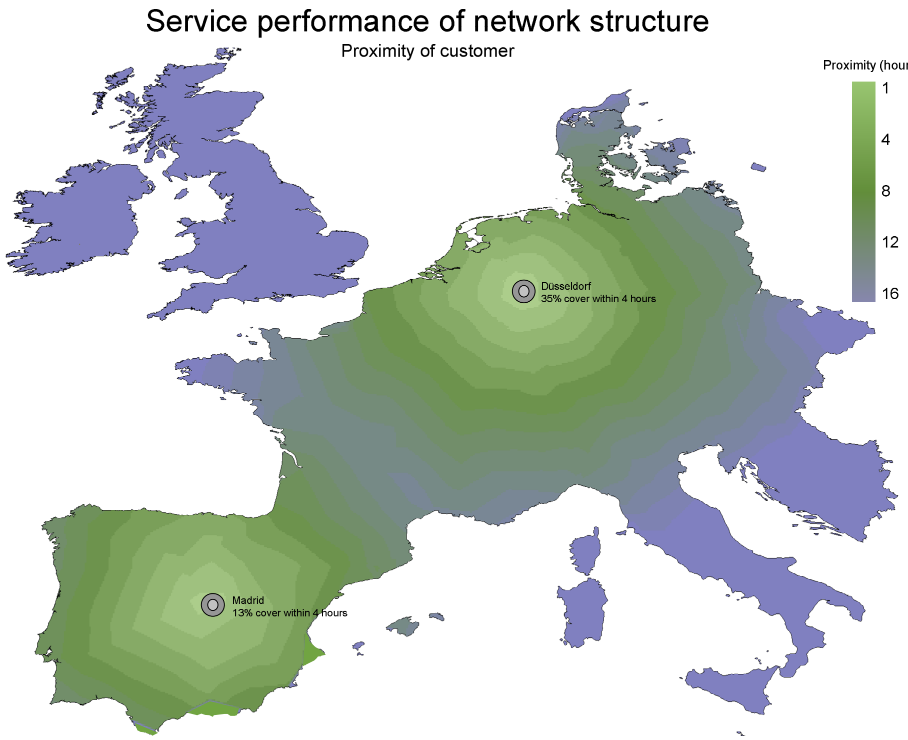

Figure 6-9: Logistics service: customer proximity of the hub network solution (2-hub network).

The proximity of the customer is still a very important quality characteristic of this type of hub network. The inter-hub transfer often takes place during the night, to be able to make the final delivery (from the hub to the customer) before a predetermined dead-line the next day. For example, before 11:00 am, 13:00 pm, or 17:00 pm. This is why in this example the 4-hour lead-time is chosen.

Finally, in Figure 6-9 the network structure of *Step 1: 2-hub network* (Figure 6-6) is depicted, illustrating the customer proximity when two hubs are opened. This network solution accommodates 8% of all shipments using only 2 services. In this network 78% of the 57 participants is located within the 4-hour lead-time (only 46 participants); illustrating the trade-off between the number of hubs (network costs) and the logistics service.

6.3 A theory on collaboration

In the previous section we discussed the scope of the design methodology, and in broad terms the way collaborative networks can be designed using a combination of system optimization and user optimization. In this section we will present the conceptual framework used for the design of collaborative logistics networks. In Figure 6-10 the overall approach to designing and evaluating a logistics network is presented, starting with the specification of the scope and objective and ending with the evaluation of the resulting network. It all starts with the specification of the objective and scope of the collaboration (step 1 in Figure 6-10); what does the organization want to achieve, what objective has to be reached? In accordance with chapter 3.4 we distinguish four key objectives of collaboration: cost or asset efficiencies, increase in customer service, marketing advantage, and profit stability or growth. Then, based on the objective, it has to be decided how this can be achieved. What type of change is required to achieve the objective? Does the network structure need to be altered, the alignment, the scheduling or the resource deployment (step 2). Then, with the objective and scope specified it has to be decided whether or not a collaboration needs to be examined (step 3).

Key elements of the conceptual framework are: (step 4) the collaboration characteristics, (step 5) the implications the collaboration has on the decision to participate based on the transaction costs δ^{tc} and additional resistances ϵ^{s} , (step 6) a network design algorithm to search for a new network solution in which economies of scale and scope in the network are achieved, and (step 7) network evaluation by simulation of the network solutions to be able to evaluate the robustness of the network solution and the impact of unreliability and timeliness.

In order to optimize any logistics network, whether or not it is a collaborative network, it is necessary to be able to calculate the costs and performance of the current situation, and calculate the performance of new network solutions in terms of costs and service, when switching to this new network alternative. A complicating factor is that the participation of firm A influences the decision to participate of firm B. Next to the design problem, it is necessary to predict the conditions under which firm A is willing to participate. If, for example, a new shuttle service is introduced that reduces the outbound transportation costs of firm A by 10%, is firm A then willing to switch from its current network solution? And if so, what does the participation of firm A mean for the other participants in terms of additional dis-economies of scale, cost reduction or complexity?

If the costs and performance of the current situation and new network solution can be calculated, it is possible to model the participation choice behavior using, for example, the discrete choice modeling methodology discussed in section 4.2. It is then necessary to be able to generate the new network alternative using an optimization technique, if possible, or heuristic approach. In our approach it is necessary to be able to find the feasible network solution but also to be able to find a development path that is feasible. In finding potential collaborative networks, the development path of such a network is as important as is the *optimal* solution or final network because it highly influences the participation decisions.

For the successful implementation of such a solution to be possible it is essential to start the development (and implementation) of the hub network with a feasible and cost-efficient network and try to improve upon it.

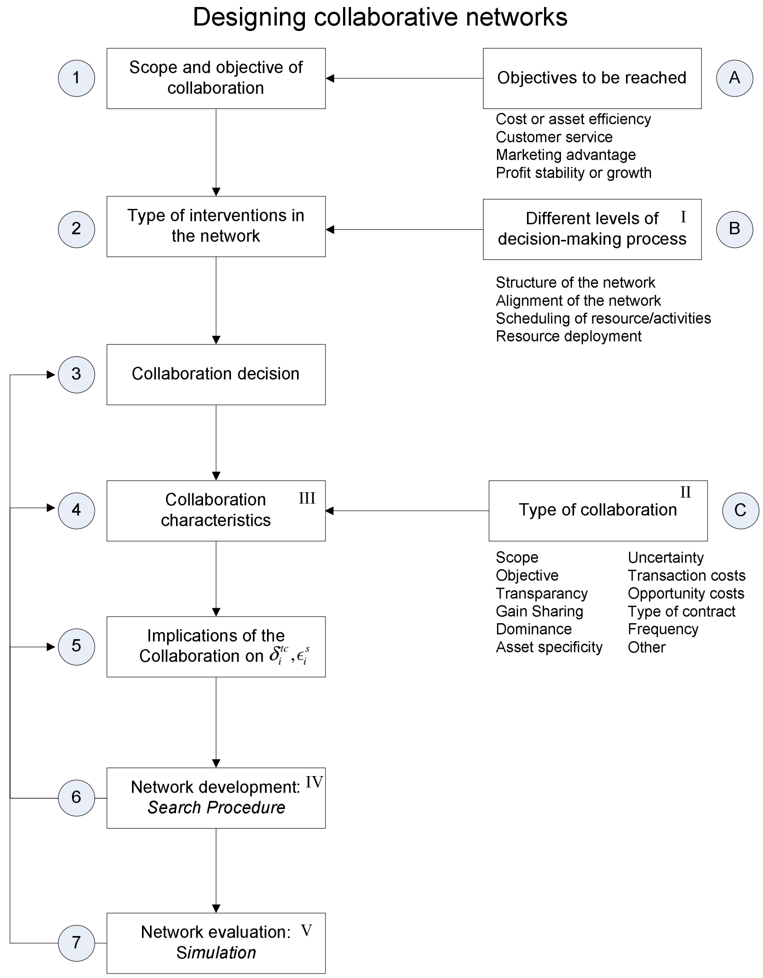

Figure 6-10: Overview of the collaborative network design approach.

I) These different levels of decision-making refer to the decisions concerning the network structure, the network alignment, the scheduling and resource deployment discussed in section 2.2.

II) See section 3.6, section 6.3.3, and section **Error! Reference source not found.** for the selection and description of the variables, and contingencies of these aspects used to describe a collaboration.

III) The network design start with a description of the collaboration that is used to calculate the implications of the collaboration on the network design.

IV) See chapter 7 for the formal model description.

V) The different network solutions are evaluated using simulation.

The sheer complexity of the design problem makes it necessary to make simplifications. In general three approaches are proposed to handle the mathematical complexity (Section 5.4.4). The first is to adopt a partial approach, whereby some aspects are simplified for mathematical convenience. The second is to find a way to separate the problem into convenient sub problems. Finally, the third approach is to recognize the inherent mathematical difficulty, and to seek a local rather than a global optimum (O'Kelly and Miller 1994; Current *et al.* 2002). It is however of great importance for the acceptance of a network solution that it can be evaluated on key aspects (costs, reliability, and robustness) that were simplified due to limits on the complexity that can be dealt with during the optimization of the network and, as we are in search of feasible networks, this final step is explicitly incorporated in the framework. In the remainder of this section we will address the decision to participate, and what decision criteria we will incorporate in our approach, based on a selection of drivers and barriers presented in section 3.4 .

6.3.1 Key characteristics of collaboration in our theory

An important element of the framework is formed by the description of the collaboration (Figure 6-10, step 4) and, thus, deriving the implications of the type of collaboration on the transaction costs and additional resistance to participate (step 5). Based on the analysis presented in Chapter 2.4 on the different aspects of collaborative networks we here summarize the key elements of collaboration we will incorporate in the network design and evaluation methodology. The aspects we will consider in the framework are the following:

(1) *Asset specificity*, i.e. the degree to which investments for the individual firm or consortium (based on the type of collaboration) are specific for a certain relation forms one of the most important factors that influences the decision as whether or not to participate in a collaboration. The following investments are taken into account: site specificity, physical asset specificity, dedicated assets, and human asset specificity. Brand name capital and temporal specificity are not taken into account when calculating the asset specificity

(2) *Frequency*, is regarded as very important from the point of view that the cost of specialized expensive governance structures and contracts will be easier to recover for large transactions of a recurring kind. Learning effects and reduced control systems we do not take into account when capitalizing the influence of *frequency* on the transaction costs

(3) *Uncertainty*, the third characteristic of a transaction is uncertainty, and the basic proposition in transaction cost analysis is that governance structures differ in their capacity to respond effectively to disturbances. As uncertainty rises regarding a buyer's future requirements, contracts become more difficult to write, and search for an in-house solution becomes more attractive.

Next to the three key elements that influence the transaction costs we introduce two additional contingencies that influence the decision to participate but are difficult to measure. The first contingency is *Dominance*. If there is a clear dominant participant the reluctance to participate for other firms is likely to be higher in cases were there is no asymmetry (see section 3.5). The second contingency is *Transparency*, which includes not only transparency in the contracts, communication and performance of the network but also meaning trust; how open the participants are to each other and share information. For example, in a Type III collaboration one would expect a higher degree of openness than in a short-term operational Type I collaboration. In section 3.3 we presented three types of collaboration with the accompanying types of contracts. Describing a collaboration starts with the objective and the scope and what is to be changed (structure, alignment, scheduling, or resource deployment). From the objective and the scope the type of collaboration can be derived (*Type I*, *Type II*, and *Type III*). Below the key characteristics we distinguish in our framework are presented:

(1) The scope and the objective of the collaboration;
(2) the type of collaboration;
(3) asset specificity;
(4) frequency;
(5) uncertainty;
(6) dominance;
(7) transparency.

These attributes of collaboration will be discussed in detail in section 6.4 where a typology based on this list is presented to characterize different collaboration initiatives and based on three recent examples of collaboration a typology will be presented.

6.3.2 Specification of the transaction costs

The measurement of the transaction costs is basically dominated by two approaches: (1) direct measurement of the magnitude of transaction costs of running a governance structure, and (2) the determination of the factors that are predicted to be responsible for comparative differences in transaction costs across governance structures, for transactions of given attributes. For ease of exposition, the former is called *Direct Measurement Approach* (DMA), and the latter the *Indirect Measurement Approach* (IMA). Certainly, as we change the method to be used, the data requirements will vary. For IMA data is required on measurable transaction attributes and on relative frequencies which governance structures use for transactions with different attributes. For DMA data is required on measurable transaction attributes, the relative sums of all transaction costs for transactions with similar attributes under different governance structures, and the absolute values of the comparatively significant elements of total transaction costs.

Data requirements can be thought of in two dimensions: the number of transactions for which data is required; and the number of dependent variables to be measured per transaction. In terms of the latter, the data requirement of the direct measurement approach (DMA) is normally higher. However, the number of transactions on which data is required will depend upon the number of transaction attributes deemed relevant. If, for instance, only one attribute is judged relevant, then both the number of transactions on which data is required and the number of elements of transaction costs needed to be measured per transaction will be less than in an analysis where multiple attributes are judged relevant, potentially varying independently and offsetting one another.

Let us assume that having a governance structure, say the market, with u categories of transaction costs, δ_u^{tc} , $\mathcal{U} = (1,...,u)$. According to the DMA, δ_u^{tc} needs to be identified first. Then, irrespective of whether those costs are to be used as explanatory variables for organization selection or simply used in the empirical comparison of transaction costs across governance structures, they need to be quantified. Summing up all the quantified items of transaction costs yields the total cost of running a governance structure. Of alternative choices, the one with minimum $\sum \delta_u^{tc}$ is regarded as most efficient. This means that in using DMA, the absolute level of elements of transaction costs, and the relative or ordinal level of total transaction costs, must be known in order to determine the efficient organization. At this point it is important to note that, although there may be many categories or elements of transaction costs (e.g. legal fees for contract writing, court costs, search costs, inspection costs, bargaining, contractor selection costs, insurances, etc.) these costs can mostly be traced to just two ultimate sources. Most transaction costs arise either as the cost of collecting information and measuring outcomes, or as the costs of opportunism, including the cost categories proposed by Williamson presented in 3.2. In contrast to DMA, the IMA stresses comparative difference. Provided that there are two alternative governance structures under review, their running costs can be expressed as δ_1^{tc} and δ_2^{tc}, and the transaction costs difference between the two alternatives can thus be formulated as follows:

$$\Delta\delta^{tc} = \delta_1^{tc} - \delta_2^{tc} = \sum_{u\in\mathcal{U}} \delta_{1,u}^{tc} - \sum_{u\in\mathcal{U}} \delta_{2,u}^{tc} = \sum_{u\in\mathcal{U}} (\delta_{1,u}^{tc} - \delta_{2,u}^{tc}) \tag{6.1}$$

It is clear that the success of DMA is dependent on two factors: (1) the completeness of the list of elements of the transaction costs, and (2), the accuracy of the measurement of each element in that list of transaction costs for both governance structures. Of course, it can be justified that the items of minor importance or significance can be ignored. It appears, therefore, that there may be some practical problems with measurement.

Not all categories of transaction costs need to be estimated. Only the categories with a first-order difference need to be calculated. The success of DMA is conditional on whether the precise estimate of these costs can be obtained empirically. In our definition the transaction costs consist of two parts: $\delta^{tc} = \delta^{tcI} + \delta^{tcII}$. The first category (I) is caused by the first round of information problems, excluding the intervention of opportunism, while the second category (II) indicates the consequential costs arising from the strategic exercise of information asymmetry by the informed party. For instance, if a manufacturer is offered the chance to participate in a hub network he can either decide to join the network or not. If the decision is made not to participate a potential costs reduction of ΔC is not realized. If the manufacturer does participate (and chooses a more vulnerable alternative), two possibilities arise: opportunistic behavior will occur or not.

However, if it takes place, the vulnerable party may either accept the hold-up offer to bear the extra payment ΔB and/or loss due to inferior quality $v(\Delta Q)$, or reject the threat of hold-up, thus causing a series of disputes, renegotiation and third-party arbitration. Except for the legal costs, the opportunity costs of delay are also important. The consequential costs due to tussling for rent are labeled c^{leg} . In the worst situation, the vulnerable party may be forced to accept the hold-up offer after struggling. From an overall perspective, the important transaction costs are real resource-incurring transaction costs, which reduce the total economic gain from the transaction. However, from the perspective of a single transaction, trying to optimize its profit behavioral uncertainty (especial opportunism) gives rise to another kind of cost - the negative difference between the promise (on the basis of which the transaction is agreed) and the delivery or outcome. We call this rent-transferring transaction costs. This type of transaction cost may either be anticipated or not. Where they are anticipated, they result in losses, due to the refusal to engage in a potentially efficient transaction. This loss (the opportunity cost) is measured by the difference between the total economic net benefit that would have accrued from the aborted transaction, in the absence of opportunism, and the economic net benefit of the best alternative arrangement or transaction chosen instead. Where they are not anticipated, they result in a loss of expected return to the transactor, which may reduce return to below opportunity costs. We can classify the elements of δ^{tcI} and δ^{tcII} according to the nature of those costs, resource-incurring or rent-transferring. By definition, δ^{tcI} is caused by the first round information problem in the absence of opportunism. All the costs used to fill up the information gap are resource-incurring transaction costs. However, this is not the case for δ^{tcII}, which contains resource-incurring transaction costs such as legal fees and opportunity cost of delay and rent-transferring transaction costs such as ΔC, extra payments (ΔB), and loss due to inferior quality $v(\Delta Q)$ (Chang and Ive 2000).

Outside the studies of economic organization, the most common way of theorizing transaction costs is to treat them as another category of cost that can be formalized in a transaction cost function analogous to a production function. In the simplest form the transaction costs function is proportional to the number or volume of transactions. The transaction costs simply play the same role as a tax, taking away a part of the revenue from the receiver. However, in our network design approach this is not the case, especially in *second round* information problems. Difficulties in measuring the quality or performance of the trading partner as well as the irreversibility and *lock-In* effect of lump-sum investments are two contributing factors to transaction problems. The transactions subject to these two problems are characterized by the involvement of the trading partner's effort to produce goods or services. Because the attributes of the transaction object, such as quality, can be changed by trading partners, its value is not only affected by the environmental uncertainty, but also by behavioral uncertainty. It is apparent that if the transaction is characterized by these last two effects modeling the transaction costs as a tax is not an option.

6.3.3 The decision to participate

The decision to participate in a collaborative network is one of the key decisions in business. It forms a key issue of this research. This decision always has to be seen in perspective with other options open to the firm (e.g. outsourcing, in-house solution or extension of the current solution) but becomes more and more relevant with the introduction of partnerships, CPFR, JIT and the collaboration concept in logistics, as discussed earlier.

Let us go back to the example presented in section 3.2, where the efficient boundary was introduced. In section 3.2 only two organizational alternatives were considered: either a firm makes a component itself or it buys it from an autonomous supplier. Thus mixed modes, such as franchising, joint ventures, etc. were disregarded. In Figure 6-11 a third option is introduced; participation in a collaboration. We consider the same two-stage production, represented by M1 and M2 and draw these as squares. Raw materials are represented by R1, R2 and R3. Supply is represented by S1, S2 and S3. Finally, distribution is denoted as D. A solid line between units represents an actual transaction and a dashed line a potential transaction. In the starting situation the focal firm, in addition to the primary manufacturing activities, takes care of distribution D. Raw materials R1 and R3 and components S1 and S3 are procured in the market. What is also procured in the market is transport T (not depicted in figure). In addition to T1 an alternative is indicated, participation in hub network H1 (the gray arrowed lines indicate interactions with other firms participating in the network).

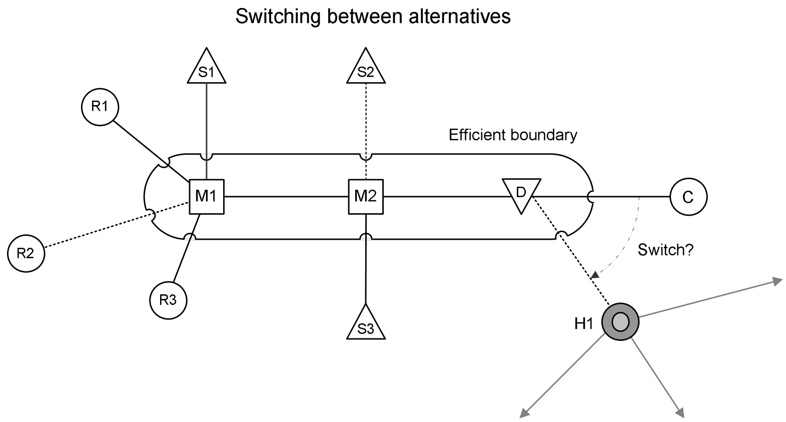

Figure 6-11: The efficient boundary of the firm: switching.

In the starting situation the focal firm has a contract with company T1 for the transportation of products from the warehouse D1 to the customer. Let the costs of this alternative be c_{ij} , and in this example the focal firm has chosen for a market solution through outsourcing due to fairly low asset specificity and transaction costs. The costs of shipping the same products via the hub network are denoted c_s^{hub} . However, switching is not without costs and involves the selection of new business partners, the transaction costs and the consequences of termination of a contract with an existing partner. Let δ^{tc} be the transaction costs involved in participating in the collaborative hub network and let ϵ^s be the capitalized resistance for switching (uncertainty, transparency, and dominance). Then if $\Delta c = c_{ij} - \left(c_s^{hub} + \delta^{tc} + \epsilon^s\right)$ exceeds a specific threshold, the firm is willing to participate in the collaboration.

Figure 6-12 depicts the cost advantage or disadvantage and revenue advantage or disadvantage a firm can have by deciding to join a collaborative network. If the effect of participating is a cost advantage the network solution can be positioned in either quadrant I or II. If there is a revenue advantage, the network solution can be positioned in either quadrant II or IV. If positioned in quadrant II there is a cost advantage as well as a revenue advantage. In this example the area (light gray and dark gray) indicates the cost-revenue ratio with which the firm decides to participate. It can be argued that if no cost and revenue advantages are to be gained, the firm is not willing to participate; a certain level of benefits needs to be present (Δc_i). Next, due to the mentioned transaction costs (δ_i^{tc}), dependent on the asset-specificity, frequency, etc. a company makes a trade-off of whether to participate or not. We assume however, that there is a certain additional resistance that firms have (not incorporated in the transaction costs) to switch due to uncertainty, dominance and transparency issues (denoted ϵ_i^s).

If the cost advantage exceeds the revenue disadvantage or the revenue advantage exceeds the cost disadvantage a firm is still willing to participate. However, as the cost advantage and revenue disadvantage increase or the revenue advantage and cost disadvantage increases, yielding the same ratio, a firm becomes more hesitant to participate (under the same condition of uncertainty, Prob^1), resulting in $\Delta c_2 > \Delta c_1$. If uncertainty increases (Prob^2) it follows that the reluctance to participate increases and the threshold rises accordingly ($\Delta c_3 > \Delta c_1$).

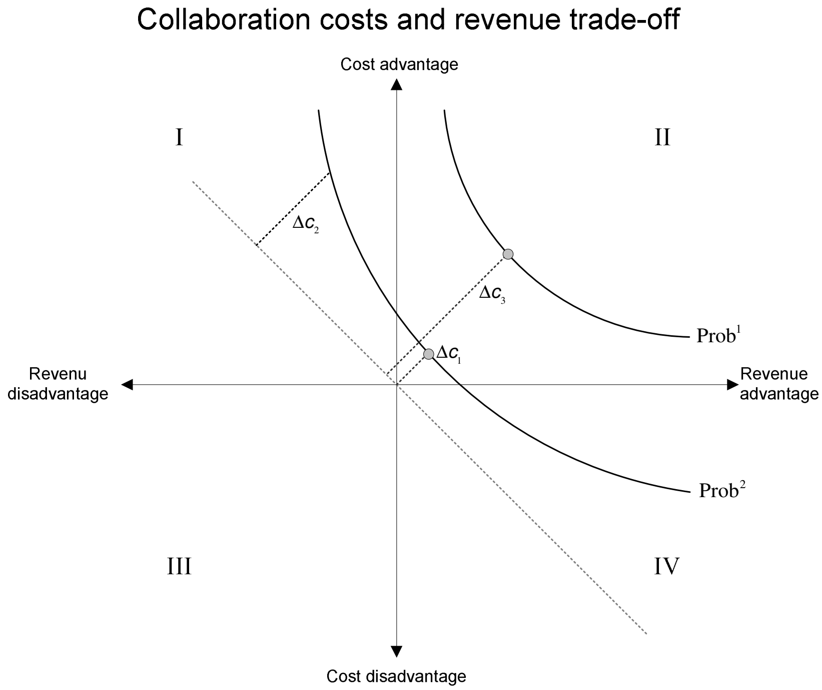

Figure 6-12: The trade-off between costs and revenues from the perspective of collaboration. Source: Ruijgrok and Groothedde (2005).

In our example the uncertainty has an increasing effect on the Δc_i but in addition we assume that Δc_i increases as the dominance of a trading partner increases, and Δc_i increases as well if transparency decreases (e.g. it becomes more difficult to measure the transaction and there is little trust between partners that information exchanged is accurate).

The decision to participate in our framework is based on Δc_i and functions as a threshold. The ratio between the costs and revenues (the total net benefits) therefore determines the decision to participate. The level of Δc_i is determined by the costs of the current network solution (in our approach denoted c_{ij}), and in the example of a collaborative hub network the shipment costs for using the hub network (denoted c_s^{hub}), and the transaction costs associated with switching between alternative network solutions (δ_i^{tc}). In addition we distinguish additional resistance (ϵ_i^s) that is associated with uncertainty, dominance and transparency. This final parameter especially can differ between participants, depending on their role in the logistics network (retailer, manufacturer, carrier, or logistics service provider), their structural embeddedness and the cost and or revenue advantage that is to be gained by participating in the collaboration. In the following section we will first present a typology of collaboration illustrated using three recent examples of collaboration. In section 6.5 we will discuss the calculation of the transaction costs and the influence the position and role of the different actors have on the level of asset specificity, transaction costs and willingness to participate: what is the effect of the role an actor plays in the network on the transaction costs and additional resistance.

6.3.4 The additional resistance to participate

In addition to transaction cost variables δ^{tcI} and δ^{tcII} (see section 6.3.2), several other variables can be identified that affect the decision to make, buy or participate in a collaboration. Although these variables are not central to transaction cost theory, and may relate more to a firm's capabilities, competitive advantage, or external environment, they influence the decision-making process. Thus, we refer to these non-transaction cost variables as the additional resistance to participate, denoted ϵ^{s} .

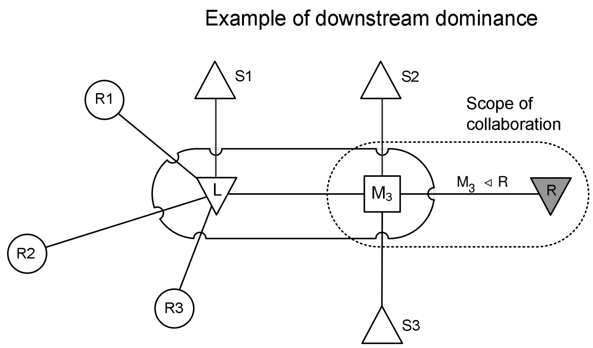

Figure 6-13: Example of downstream dominance that will increase the resistance (ϵ^{s}) to participate of the manufacturers.

Transaction costs increase when asset specificity increases due to opportunism, defined by Williamson (1985) as "*self-interest seeking with guile*". Although investments in specialization boost productivity, the incentive to make a transaction-specific investment is tempered by the fact that the more specialized a resource becomes the lower its value in alternative uses. The contingent value of a specialized resource exposes its owner to a greater risk of opportunism than the owner of a generalized resource (Klein *et al*., 1978). This *risk* is usually covered by the transaction costs, in particular δ^{tcII} , but as we discussed earlier in respect to the dominance of partners (see section 3.5), the lack of transparency and uncertainties are not always adequately covered in the transaction costs. To protect themselves against these hazards, power and lack of transparency, actors can employ a variety of safeguards. Although contracts are viewed, however, as the primary means for safeguarding transactions, (and included in δ^{tcI} and δ^{tcII}).

In chapter 3 these contingencies were discussed; *dominance* and *transparency*. Both contingencies are difficult to measure and are incorporated in the design process, but we keep the possibilities open of computing the impact of these aspects on the resulting network solutions. In Figure 6-13 an example of a collaboration is depicted between three manufacturers and one retailer. The dominance of the retailer, in this example, has an increasing effect on the resistance to participate of the manufacturers. This can lead to higher transaction costs through longer negotiations and strict contracts or through a higher ϵ^S that is not made explicit in the contract. The same effect is to be expected if it is very difficult to measure the benefits and very complex to determine the gain-sharing structure. In other words: how can the benefits of the collaboration be shared between the participating actors? If this aspect is unclear to the participants it can be argued that either the transaction costs will increase through lengthy negotiations or the additional resistance ϵ^S will increase.

6.4 A typology of collaboration

In the previous sections the key drivers and contingencies of collaboration were discussed. Based on this description and keeping in mind the objective of designing collaborative networks we will now present a typology of collaboration. In this typology we focus on those aspects of collaboration that have a strong influence on the network design and that will be incorporated in the design methodology.

Based on the types of collaboration presented in Section 3.3 by Lambert *et al.* (1997) we distinguish three types of collaboration Type I, II, and III. Next to these three types, we indicate, using a six position notation, the scope and objective of the collaboration. In this notation the first four positions correspond with the four levels of decision-making in network design discussed in section 2.2 (structure, alignment, scheduling and resources), the fifth position is reserved for the objective of the collaboration (cost or asset efficiency, customer service, marketing advantage, or profit stability or growth) and the sixth position is reserved for the type of collaboration (I,II, or III)[12]. The scope is then indicated using an S at the first position for collaboration aimed at the structure of the network, an A at the second position if aimed at the alignment of the network, Sc if aimed at scheduling, and R if the collaboration aims to share the resources in the network. If a dot is included in the notation ($\bullet$), the collaboration is not aimed at this aspect of the logistics network. For example, $\bullet / A / Sc / \bullet / \text{costs}, II$, indicates a type II collaboration, with impact on the alignment (A) and scheduling (Sc) of the network and the objective is to minimize the costs.

For the fifth position we distinguish four key objectives, in accordance with the drivers of collaboration discussed in section 3.4. The objective of the first category is to achieve cost or asset efficiencies, indicated by either (*costs*) or (*assets*). The second category focuses on customer service, indicated by, for example (*lead-time*), (*reliability*), or (*inventory*). The third category focuses on marketing, and the objectives are to enhance an organization's marketing mix (*mix*), entry into new markets (*markets*), or better access to technology and innovation (*technology*). Finally, the fourth category objectives are increase in profit (*profit*), or stability (*stability*).

In Figure 6-14 the boundary of our focal firm is again depicted with two stages of manufacturing. There are two distinct production stages in the logistics network, represented by M1 and M2. Raw materials are represented by R1, R2 and R3. Component supply is represented by S1 and S2. Distribution is denoted by D. Finally, a solid line between units

[12] The three types of collaboration mentioned here correspond with a Type I (operational), Type II (coordination), or Type III (network) collaboration.

represents an actual transaction and a dashed line a potential transaction, and the boundary of the firm is drawn as a closed curve that includes those activities that the firm does for itself. The closed curve that defines the efficient boundary of the firm in Figure 6-14 includes the primary manufacturing activities. Distribution D1, raw materials R1 and R3 and components S1 and S3 are procured in the market. In addition there is a collaboration depicted in the figure. A closed dotted curve indicates the scope of the collaboration. In this example the collaboration includes M2 and L2 (logistics service provider). Next to the scope of the collaboration, the subscript indicates the number of actors of a specific type. In this example manufacturing M2 consists of a single location and L consists of two logistics service providers (indicated by the subscripted 2).

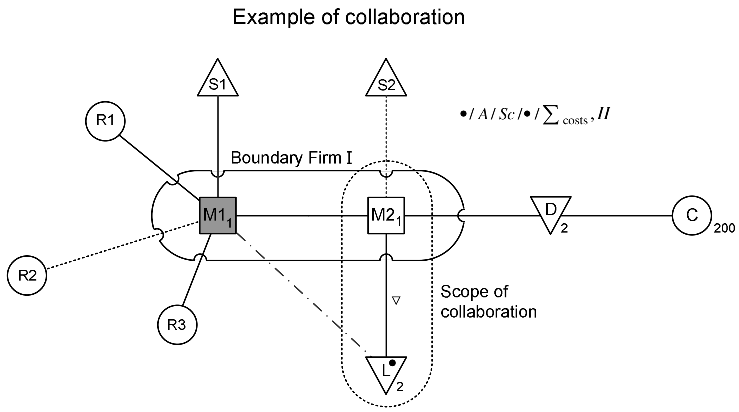

Figure 6-14: Schematic representation of collaboration between a manufacturing company and two logistics service providers

The dashed-dotted line from L to M1 indicates information exchange between these actors. In this example the service provider (L) collaborates with M2 in a type II collaboration and exchanges information with the manufacturer M1. Another important aspect of a collaboration is the combination of actors, and their relations to one another. Issues like symmetry of the relationship, power, conflict, buyer-seller relations, dependence etc. have been discussed at length in the literature (see section 3.1). Thus, in accordance with the regimes presented in section 3.5, the dominant actors are indicated, giving an impression of the upstream or downstream dominance, interdependence and independence of the participants. The dominant partners are indicated by a gray-filled symbol, in our example $M1_1$. Finally, the actor, or actors, that govern the collaboration is always indicated by a superscripted dot. In the example presented in Figure 6-14 the service providers $L_2^{\bullet}$ govern the collaboration.

Obviously this example is arbitrary and merely illustrative. It also oversimplifies greatly. It is relatively easy, however, to elaborate the scheme to add to the core, to consider additional components, to include several material stages, and consider backward integration into these, to breakdown distribution etc. We use this schematic representation to illustrate the key characteristics of the collaboration. To illustrate the typology and elaborate on several key issues in collaborative logistics networks we present in subsequent subsections three recent initiatives, in which the three different types of collaboration will be discussed. Two of these initiatives (Type I and Type III) have already been implemented. Before we discuss the three types of collaboration we present the initiatives according to the typology presented above. The first initiative is a *Type I*, operational collaboration between two manufacturers and a logistics service provider. In Figure 6-15 the schematic representation is presented. Initially there were two distribution centers used (D_2), but in the new situation a single distribution center is operational. The collaboration is governed by ACR logistics (Figure 6-15). The second example is a concept with extensive consequences for the alignment of the logistics network and the inventory levels. It requires a high level of information sharing and transparency, and is a *Type II* collaboration between manufacturers (8) and retailers (2) (Figure 6-16).

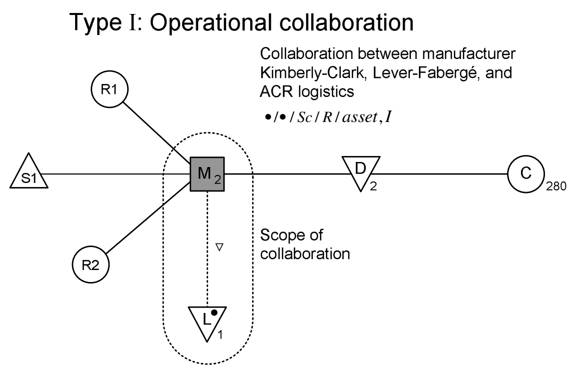

Figure 6-15: Schematic representation of the operational collaboration between manufacturer and logistics service provider ACR Logistics.

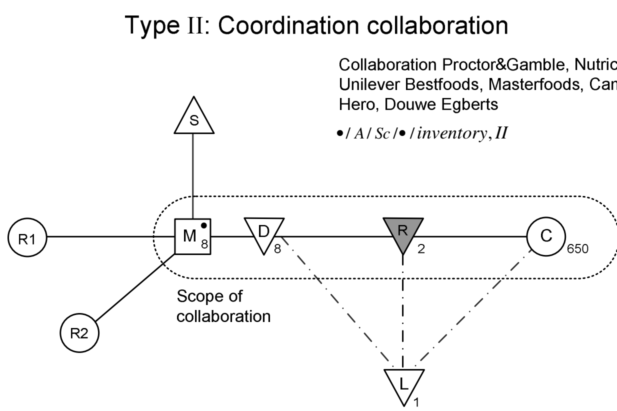

Figure 6-16: Schematic representation of the coordination collaboration between manufacturers, retailers, and service providers.

The third example we will discuss is a collaboration between three manufacturers of frozen food which collaborate with a logistics service provider and can be classified as a *Type III* network collaboration (Figure 6-17), changing the network structure considerably. In Figure 6-17 three logistic service providers are included ($L2_3$) representing the logistics service providers that were contracted in the starting situation before participating in the collaboration. By starting this initiative a considerable reduction in physical distribution costs could be realized and in addition, through the economies of scale, the logistics service increased (in terms of lead-time and frequency) without any additional investments

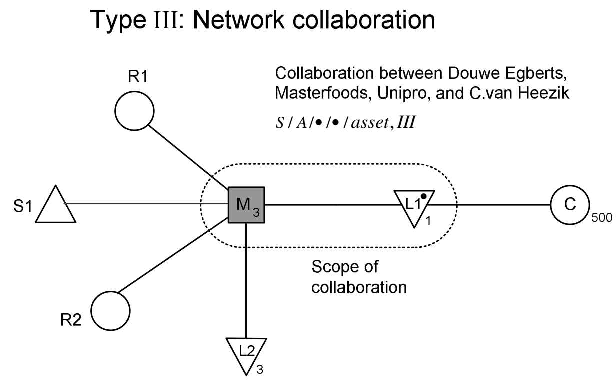

Figure 6-17: Schematic representation of the network collaboration between manufacturers and a logistics service provider.

6.4.1 Type I: *Operational Collaboration*

A first example of collaboration is the partnership between Kimberly-Clark, Lever Fabergé, and ACR logistics (former Hays-Logistics). This example is a typical horizontal collaboration as both Kimberly-Clark and Lever-Fabergé are major multinationals in the home and personal care market (Van der Drift and Van der Berg 2004). Kimberly-Clark is a prominent global manufacturer of personal care products (74% of sales) and products for the business to business segment (26% of sales). Some of their major brands are Page, Kleenex, Huggies, Kotex and Depend. 19% of their turnover is realized in Europe, 60% in North America, 11% in Asia, and 10% in other countries. Before the collaboration between these three companies Kimberly-Clark operated from a warehouse in Ede, with annually 400,000 pallets inbound and outbound, for the physical distribution of high volume products to about 200 customers in the Netherlands, to mainly retail warehouses and wholesalers (Figure 6-15).

Lever-Fabergé, the second participant, is part of Unilever, with about 265,000 employees in 90 countries, and produces home and personal care products. Prominent brands owned by Lever-Fabergé are Sun, Cif, and Axe. In 1998 the activities of Lever and Elida Andrelon where consolidated into Lever-Fabergé and they became the largest supplier of household and personal care products in the Dutch market. In the Netherlands they operated from a warehouse located in Veghel, with annually 320,000 pallets inbound and outbound for the physical distribution to approximately 170 customers, again mainly retailers and wholesalers. Together with their logistic service provider ACR Logistics, both manufacturers decided to centralize their inventory and to operate from a warehouse in Raamsdonkveer, built by ACR

Logistics and with a capacity of 35,000 pallets (Figure 6-18).[13] The objective of this collaboration was a cost reduction in transportation of 10-15% and a significant inventory reduction at the retailer. A second objective was to increase the delivery frequency and achieve economies of scale in the warehouse, order-picking and handling operations.

Figure 6-18: Overview of warehouse locations and customers of Lever-Fabergé and Kimberly-Clark.

The total investment was approximately 25 million euro for the building and Automated Layer Picking equipment (ALP), installed at this location. Both the manufacturers and the service provider invested in the collaboration. ACR-Logistics built and financed the warehouse, Kimberly-Clark and Lever Fabergé invested in the automated layer picking

[13] All facilities, warehouses and retail outlets as well as attributes (like the indications of the inbound and outbound volumes) depicted in the figure are solely based on publicly available information. This also applies for the figures presented in section 6.4.2 and section 6.4.3.

machine (APL). Although both manufacturers changed their inventory location (from Ede and Veghel to Raamdonskveer) and the contract term is relatively long (approximately 5 years) we do not consider this to be a *Type III* collaboration (network collaboration) although the structure of the logistics network is changed; the location of the inventory altered from Ede and Veghel to Raamsdonkveer, the collaboration has an operational scope.

The logistics service provider is still ACR logistics for both parties. The collaboration focused on the utilization of the assets, the warehouse, handling equipment, vehicle fleet and order-picking equipment. This does not in any way mean that this is considered to be a 'simple' collaboration because the implementation of collaboration of this scale, aimed at cost reduction and asset utilization, is very complex.

6.4.2 Type II: *Coordination Collaboration*

A second example of collaboration, not yet implemented, is a proposed partnership between manufactures and retailers in the food-sector aimed at the reduction of the logistics costs primarily by reducing the inventory. This initiative, referred to as *synchronization of the supply chain*, was supported by Klict[14] and was a part of the project "*van Maatwerk naar Confectie*" (from tailor-made to confection).

This project focused on the alignment of the network; where to locate the inventory and what the replenishment frequency of the warehouse should be (Van der Vlist 2003; Deloitte and Touche 2002). We consider this to be a *Type II* collaboration ($\bullet / A / Sc / \bullet / \sum_{\text{costs}}, II$). Companies involved are Schuitema, Jumbo supermarkets, Proctor and Gamble, ACR Logistics, Unilever Bestfoods, Masterfoods, and during the project extended to include Nestlé, Douwe Egberts, Campina, Hero, and Nutricia. The key locations of these retailers and manufacturers are depicted in Figure 6-19. The current logistics network in the retail is usually multi-echelon consisting of the manufacturing locations, production and retail warehouses, and the retail outlets, often with daily ordering. In addition, usually delivery time windows need to be taken into account.

In this concept the inventory level at the retailer is made visible for the manufacturer and based on this information the manufacturer determines the production quantity and timing of this production. Immediately after the batch is produced it is shipped to the retailer, hereby passing the production warehouse and lessening the time pressure in the entire pipeline. Next the shipments can be made in full pallets loads and/or Full Truck Loads (FTL).

The inventory is located closer to the customer and therefore it can be argued that the response times decrease. Although the inventory at the retailer increases, the overall inventory in the network decreases. A realistic business case based on the information provided by these participants showed that a reduction of between 24% and 36% of logistics costs is possible (Deloitte and Touche, 2002). In this collaboration the specific assets are primarily the increased inventory space at the retailer. The benefits for the manufacturer are about -60% in inventory costs (against +22% for the retailer). The difficulty in this

[14] Klict (Chain networks, Clusters and Information Communication Technology) is a project organization that stimulates the development and application of knowledge in the area of chain and network science. Within this process, it serves as a broker and a 'liaison office' between the business world, knowledge institutes, social organizations and the government.

collaboration is on the one hand the downstream dominance of the retailer in the appropriation of the value, and on the other hand the uncertainty for the retailer in actually receiving the benefits.

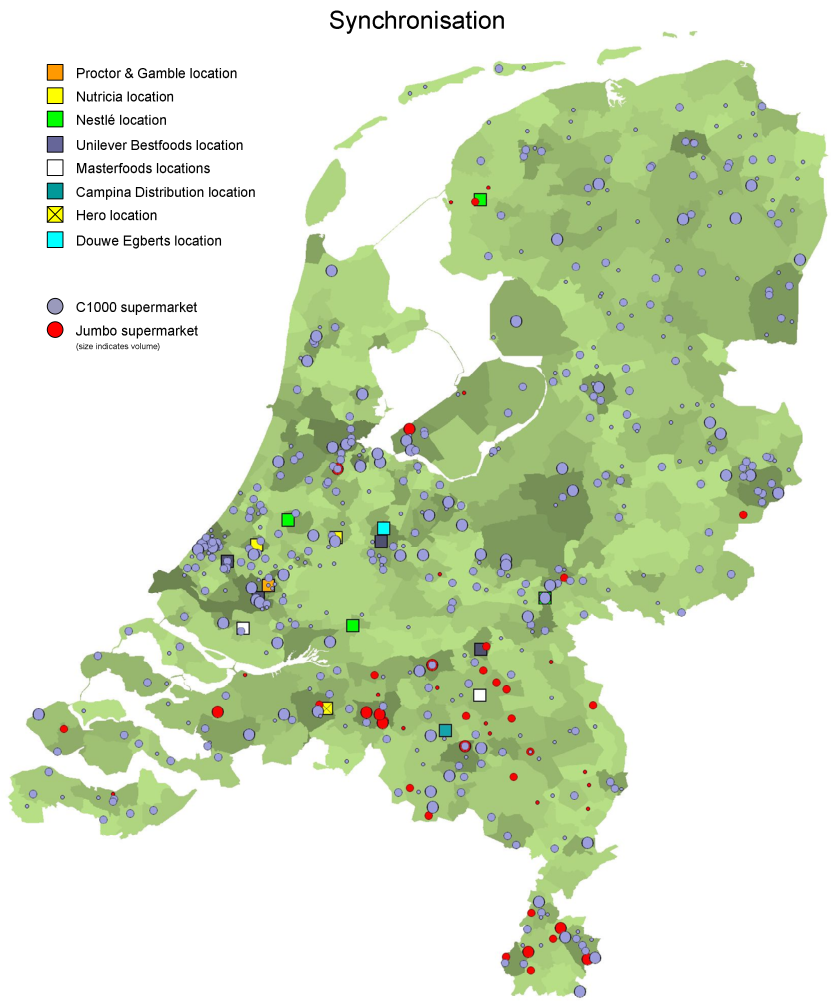

Figure 6-19: Overview of warehouse locations and customers in the synchronization case.

Transparency and gain-sharing is a vital aspect of this collaboration. This initiative is an excellent example of an innovative concept that yields considerable cost reductions, yet is difficult to implement due to contingencies like trust, dominance, measurability, and gain sharing.

6.4.3 Type III: *Network Collaboration*

The final example of collaboration we present is *Project Koud*, an initiative of three manufacturers and a logistics service provider; Douwe Egberts, Unilever Masterfoods, Unipro and C.van Heezik (Figure 6-20).

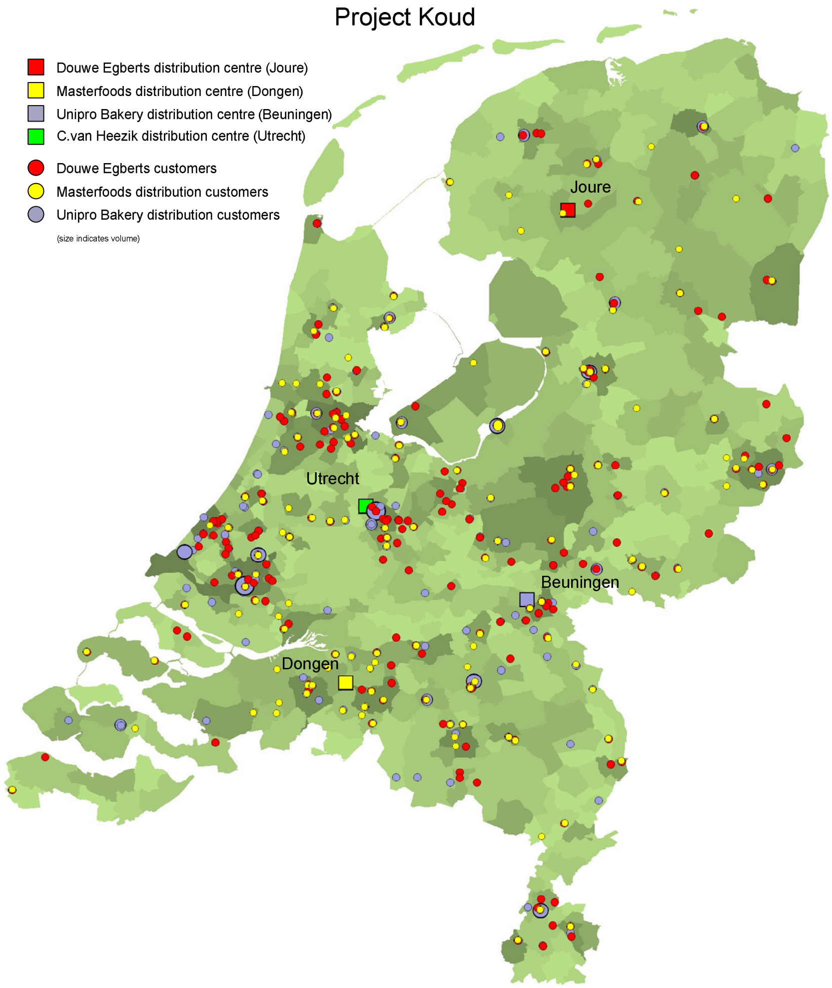

Figure 6-20: Overview of warehouse locations and customers. Source: Groothedde (2003).

This project, supported by SenterNovem (the agency for sustainable development for the ministry of Economic Affairs), aimed to reduce the logistics costs of the three participating manufacturers through centralization of their inventory and their transport ($S/A/\bullet/\bullet/\sum_{\text{costs}}, III$). In the initial network all three manufacturers shipped FTLs from their manufacturing sites to warehouses located in Joure, Dongen en Beuningen respectively (see Figure 6-20). These warehouses were operated by separate logistic service providers. In the new situation FTLs from the production sites of all three manufacturers are shipped to a common single warehouse, merging their Dutch logistical operations for frozen products. These products from all three firms are stored and frozen at a new distribution center in Utrecht by logistical service provider C.van Heezik. Ice-products from Masterfoods, bread and bakery products from Unipro and frozen coffee concentrate for Douwe Egberts. As from autumn 2004, retail outlets have received Douwe Egberts coffee and Unipro Bakery products from the same lorry and at the same time. Masterfoods was scheduled to join the scheme from March 2005. The number of participants in the scheme might even be increased further in the future. Distribution costs for frozen products are high, and other firms might well show an interest in the concept as a viable means of cutting down on costs. The objective was a cost reduction in the transportation of 10-15% and an inventory reduction of all three participants. An analysis of the order information for 2001 showed considerable overlap in address and zip-code between the participants. For Douwe Egberts almost 53% of the orders, 70% of the Masterfoods orders and 70% of the orders of Unipro had overlap with one of the other participants. If looked at the overlap in zip-code (overlap in orders based on the zip code of the customer) the percentages were even higher 65%, 76%, and 82% (Groothedde 2003).

As well as the reduction of three separate warehouses to one central warehouse located in Utrecht it appeared, based on the order information that a reduction in the vehicle kilometers of 30% could be realized due to the overlap in customers. The asset specificity rests solely with the service provider C.van Heezik who built and exploits this warehouse. To reduce the uncertainty for C.van Heezik a contract was used that stated that for the next three years the three manufacturers will make use of it. Next to the relatively long term of this contract the asset specificity for the service provider is further reduced because the warehouse is also used for the storage of products for other retailers (for example Plusmarkt and Aldi). Spreading the risk over several transactions.

6.4.4 Conclusions - case studies in collaboration

In this section the key characteristics and the typology of collaboration were presented and illustrated using three examples of collaboration in the Netherlands. If we keep the objective of this research in mind it is paramount that the type of collaboration has great influence on the transaction costs and the additional resistance we discussed in subsection 6.3.4. We therefore focused on classifying the different forms of collaborations and contingencies. Especially dominance, transparency and uncertainty are issues of great importance though very difficult to describe. Even more difficult it is to quantify these variables. However, a methodology that can provide insight into the effects of transaction cost, or dominance, transparency or uncertainty (high or low) on the network design can be of great importance during the decision-making process.

In Figure 6-21 the different steps that need to be taken when classifying a collaboration are illustrated (similar to the schedule presented in Figure 6-10). Firstly, the objective and scope are specified; what does the organization want to achieve, what objective has to be reached? (cost or asset efficiencies, increase in customer service, marketing advantage, and profit stability or growth). Then based on the objective it has to be decided how this can be achieved through network design decisions. What types of interventions are required to achieve the objective? Does the network structure need to be altered (step 2a), the alignment (step 2b), or the scheduling (step 2c), or the resource deployment (step 2d). In Figure 6-21 a list of different interventions is listed that could be the focus (B). This is not a comprehensive list but illustrates the different changes that can be made in the logistics network.

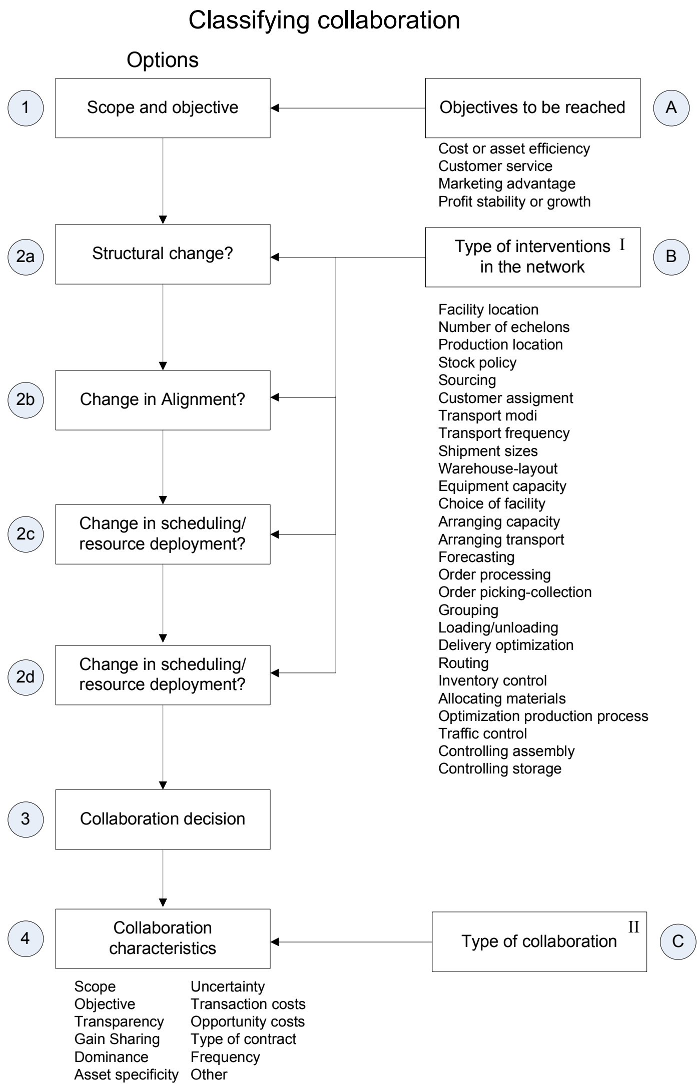

Figure 6-21: Overview of the steps to classify the type of collaboration

I) The different levels of decision-making must be translated into the different aspects listed.
II) The different types of collaboration and the implications on the collaboration characteristics (I,II, and III) is considered input of the analysis.

With the objective and scope specified it has to be decided whether or not a collaboration needs to be examined (step 3). Then, given the scope and objective the type of collaboration needs to be specified in terms of asset specificity, frequency, type, dominance, etc. (the characteristics discussed in section 6.3.1). To illustrate the developed typology above, we listed several initiatives and classified these collaborations using the steps presented in Figure 6-21. In Appendix A:Initiatives in collaboration these initiatives are presented and a brief description of the collaboration, the objective and the scope and the type of collaboration is presented. In addition the specific change in structure, alignment, scheduling, or resource deployment are included.

Throughout this dissertation we discuss three types of collaboration: Type I in which the partners collaborate on an operational level, Type II collaboration in which the partners coordinate their efforts, and a Type III collaboration with long term commitments between the different partners (usually changing the network structure). The examples discussed in Appendix A:Initiatives in collaboration, can be classified a in either Type I, II, or III. It can, however, be argued that collaborative networks go one step beyond a Type III collaboration in the sense that this type of collaboration is not only structural in nature but extends throughout the logistics network and involves multiple actors. It is possible to have a Type III collaboration with only two actors which is impossible for a Type IV.

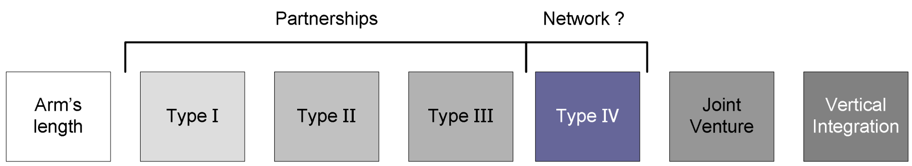

Figure 6-22: An additional form of collaboration: Type IV.

We only mention this new type of network collaboration because of the need for a comprehensive typology capable of classifying all types of collaboration and initiatives. In the remainder of this dissertation we focus on Type I, II, and Type III initiatives as these first three suffice to describe the case studies and initiatives presented in this dissertation. In the case-study discussed in Chapter 8 one of the development stages is close to a Type IV collaboration. In Figure 6-22 the different types of collaboration, based on Lambert *et al*. (1997) are again depicted but we added a fourth type of collaboration, we named a Type IV network collaboration.

6.5 Distribution of the transaction costs

In the previous section we discussed the typology of collaboration based on the set of characteristics of collaboration; scope, objective, asset specificity, etc., and illustrated this typology by discussing three case studies. In 6.3.3 we already discussed the contingencies influencing an actor's decision to participate. In this section we will illustrate the methodology we will use to derive the participant-specific switching costs and the impact the different contingencies and roles of the participants have on these costs. We will calculate the transaction costs and additional resistances that participant might have, given their role and characteristics. Based on the characteristics of the collaboration, in this example a Type II collaboration between two manufacturers, a logistics service provider and a single retailer, we will calculate the asset specificity, the transaction costs, and the additional resistance the participants might have. In Figure 6-23 our example collaboration between the four actors is illustrated. The two manufacturers, denoted M_2, the logistics service provider (L), and retailer (R) participate in an initiative to minimize the pipeline inventory (similar to the example presented in 6.4.2). The logistics service provider (L) governs and initiates the collaboration and we assume the service provider needs to invest heavily in information technology and a dedicated warehouse. The transaction costs of the service provider are $\delta^{tcI} = \left(c^{sc} + c^{bc} + c^{ec}\right)$, in which search costs (c^{sc}), bargaining costs (c^{bc}), and enforcement costs (c^{ec}) are included. As the service provider initiates this collaboration the search costs (c^{sc}) can become considerable (sales manager, assistant, legal advisor, and operational manager, etc.). For illustration purposes we assume these costs to be $\delta^{tcI} = \left(80,000 + 60,000 + 45,000\right)$. To be able to implement the concept in which the inventory is centralized a newly built warehouse is exploited and the service provider needs to invest in an information and planning system to be able to govern the collaboration.

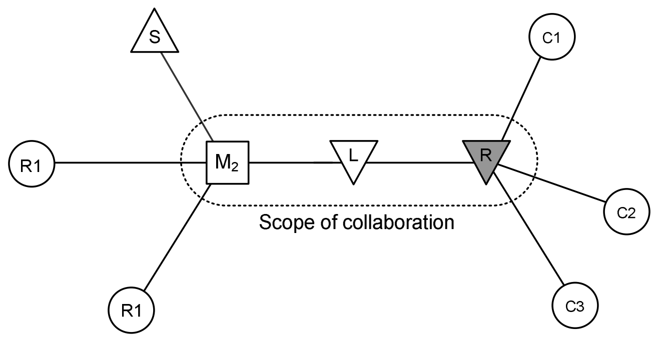

Figure 6-23: example of collaboration between 2 manufacturers, a service provider and a retailer.

The annual fixed and variable costs for the warehousing operation are €560,000/year, €150,000/year for equipment, and the annual cost for the dedicated information system are €180,000 (investment, development, training, and operations). In total the service provider needs to invest in the collaboration an initial €185,000, and for the contract period of 5 years an annual €890,000. Although these costs are estimated costs, they are realistic and illustrate the asset specificity that the service provider needs to be willing and able to invest in before the collaboration can be realized. In this example both manufacturers have to invest in information technology and minor changes in their production process. Their transaction costs consist of search costs, bargaining costs and enforcement costs, but as the initiative and governance lays with the service provider these transaction costs are less (in comparison with this same service provider). The retailer only makes some search costs, bargaining costs and enforcement costs so there is relative uncertainty associated with participating and, given their dominant position, there is little resistance to participate to be expected. In Figure 6-24 the trade-off between the disadvantages and advantages is illustrated for the four actors in the network. In our example the service provider has the highest resistance to participate (Δc_i) due to the high asset specificity and uncertainty. The fact that the retailer has a dominant position in this constellation also increases the resistance. It is therefore quite logical that the service provider will want safeguards. Both manufacturers are in the same position but will have a lower threshold due to the lower asset specificity and transaction costs. The two curves of both manufacturers are not similar due to the different situations they are in (in terms of volume, frequency, products) and therefore the costs and benefits differ. In Figure 6-25 the trade-off curve is again depicted. In this figure several groups are distinguished. First of all there is a group $\mathcal{A}$, e.g. consisting of 6 participants, denoted by the green circles for which there is a distinctive revenue and cost advantage. For group $\mathcal{B}$, with 7 participants there is no distinctive revenue advantage when participating but by joining the collaboration these actors can achieve a cost advantage, and given the level of this cost advantage they all decide to do so. A third group, group $\mathcal{C}$, have no cost or revenue advantage and will not participate.

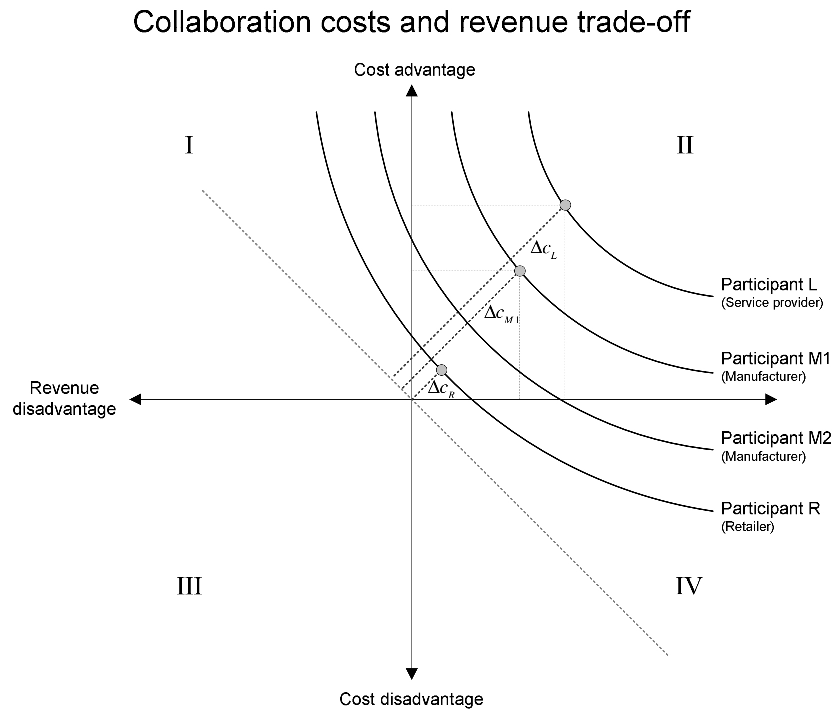

Figure 6-24: trade off between costs and revenues based on the role of the actor.

For illustration purposes we also depicted a participant $\mathcal{D}$, for which joining the network does not yield considerable cost or revenue advantage. However, the affiliation of participant $\mathcal{D}$ could be of importance for the network development. It might be worthwhile distributing the cost and revenue benefits in such a way that participant $\mathcal{D}$ is offered an additional cost or benefit advantage. Up to the point participant $\mathcal{D}$ decides to participate. This process of optimizing the gain-sharing is outside the scope of this dissertation but could well yield an additional improvement in the network performance, prolonging the development path and increasing the total logistics cost reduction. For additional information concerning these issues we refer to Vos *et al.* (2002) and Cruijssen *et al*. (2004) in which different strategies to share these gains are evaluated.

In this chapter we discussed the key issues in designing and evaluating a collaborative logistics network and presented a typology that can help us identify and illustrate these characteristics of a collaboration that influence the design of the logistics network. In addition we presented a comprehensive framework for the design and evaluation of collaborative logistics networks. We focused on classifying the different forms of collaborations and contingencies. Especially dominance, transparency and uncertainty are issues of great importance though very difficult to describe. Even more difficult it is to quantify these variables. However, a methodology that can provide insight into the effects of transaction cost, or dominance, transparency or uncertainty (high or low) on the network design can be of great importance during the decision-making process.

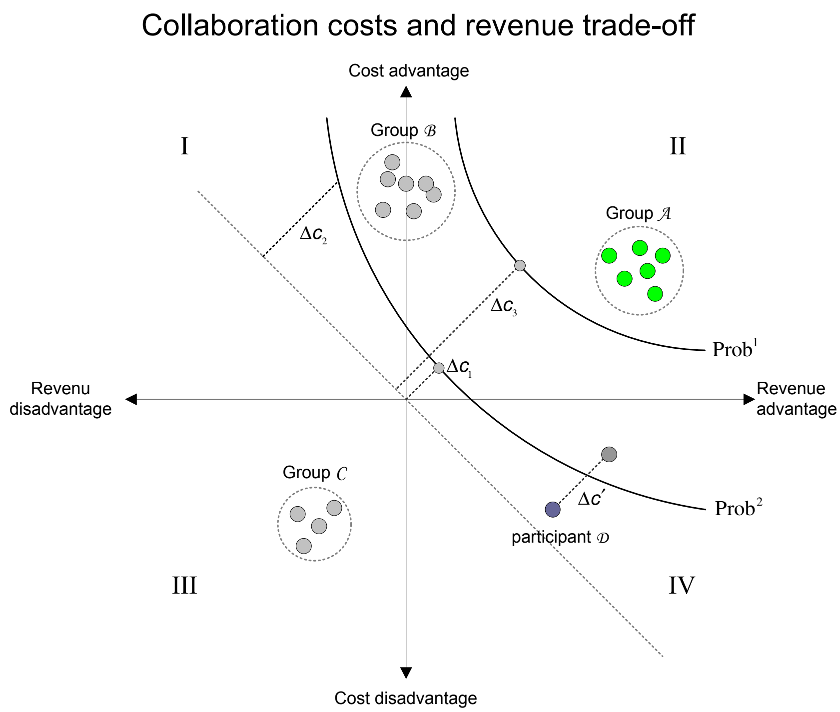

Figure 6-25: Gain sharing and distribution of the cots and benefits.

Illustrated by the list of initiatives, presented in the previous section there are all sorts of collaboration initiatives with different scopes and objectives. Based on three types of collaboration we will design collaborative networks even though we discussed the possibility there might be an additional type of collaboration (Type IV). We limit ourselves in this dissertation to the three types we discussed in Chapter 3 and Chapter 6. We focus on a specific network type and that is the hub network in which the participants collaborate. Our design question is therefore closely related to the hub network design problem, discussed in section 5.4.

7 Formal model description for hub network design

In the previous chapters we discussed modeling the decision-making in logistics and the methods described in literature to design logistics networks, in particular hub networks. Using the state of the art on hub-network design and combining this with *Transaction Cost Analysis* to model the behavior of firms in choosing among network alternatives, we presented our conceptual framework to design a collaborative network in chapter 6. In this chapter we will present the translation of this framework into a formal model description in which the following steps are presented: 1) the decision-making process, 2) the search procedure for the feasible networks, 3) the appropriate costs functions, and 4) the solution procedure.

In section 7.1 we present the model structure, in which the different steps will be discussed in detail. In the following section 7.2 the design problem, formulated as a cost minimization problem, will be discussed. In section 7.3 the costs functions on which the trade-off between the different alternatives is based, and the decision of actors whether or not to participate in a consortium is discussed. In section 0 the optimization methodology used to generate the network solutions will be presented. This methodology, *Simulated Annealing*, is evaluated using two well-documented examples and compared with other solution procedures. Special attention will be given to the development path of the hub network during the search for the feasible solution. As we search for a feasible network solution the path towards this final solution is very important. It is of great importance that during the development of the network the collaboration consortium[15] can have a say in the admittance of new participants. This chapter is concluded with a description of different network development strategies and some comments on the case study.

7.1 The model structure

In Figure 7-1 the structure of the overall modeling approach is illustrated. In this figure seven steps are distinguished that will be discussed in the following section. The design starts with the description of the current situation in terms of locations, flows, product characteristics and mode information of the potential participants, resulting in a description of the current logistics networks of potential participants. This description is used as a reference for the network design phase (Step 1 Figure 7-1). Based on this input, the costs of the current situation are then calculated (e.g. inventory, transportation, handling, warehousing, administration costs) for each individual participant. Given the mode of transport used on the

[15] By consortium we refer to the participants already making using if the hub network or the *launching members*.

origin-destination relations, the appropriate cost function to calculate the costs is used. Next to the transportation costs the facility, inventory, and handling costs are calculated. In section 7.3 the incorporated costs will be discussed.

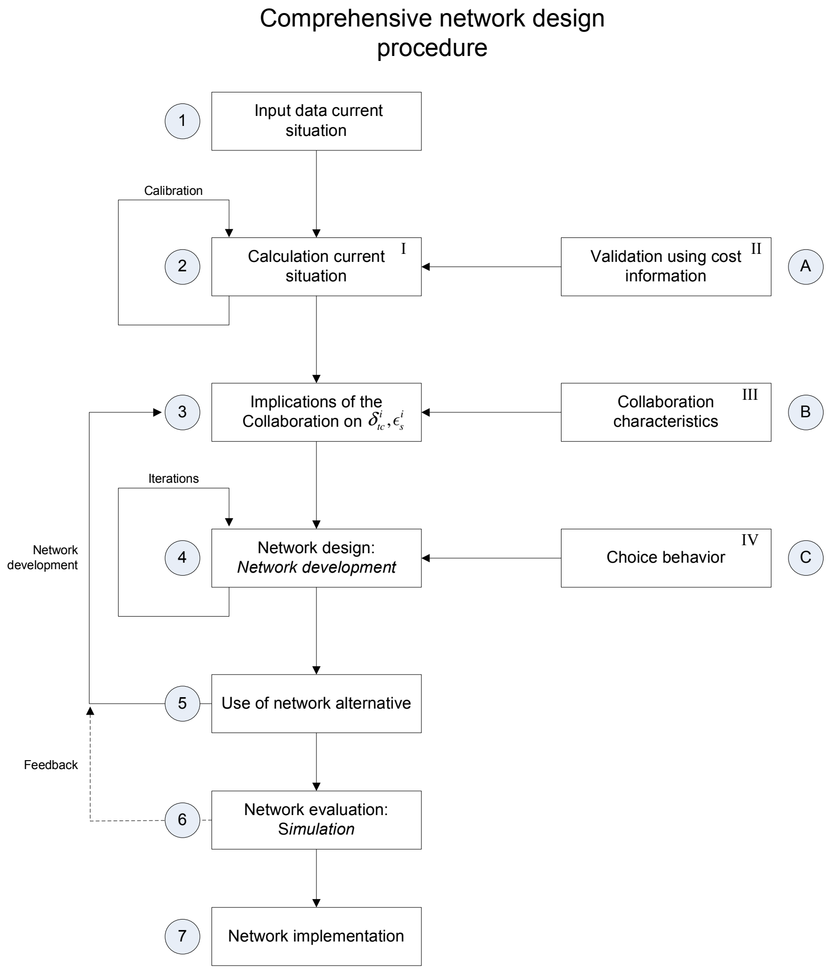

Figure 7-1: Design procedure for a collaborative logistics network.

I) The methodology to calculate these costs is based on activity based costing discussed in 5.1 and available benchmarks (NEA 2005; AC-Nielsen 2003; Groothedde 2004a).
II) These costs are provided by the participating firms and are used to validate and calibrate the cost functions used. If necessary the model is calibrated.
III) Based on the characteristics described in Chapter 3 and Chapter 6, i.e. type of coordination, asset specificity, uncertainty, frequency, dominance, and contract.
IV) Modeling the choice behavior of the potential participants we can make use of either a deterministic or probabilistic model as discussed in section 4.2.

These calculated costs are then validated using information provided by the potential participants (denoted A in Figure 7-1). The next step is to describe the type of collaboration (B) and to translate the characteristics of non-tangible model parameters for all potential participants (e.g. translated into the transaction costs δ_i^{tc} , and the additional resistance, ϵ_i^s).

Note that these are indexed because the impact for all potential participants is estimated for every alternative network solution. If this impact of the collaboration on the transaction costs and resistance is estimated it is then possible to estimate the costs and implications of a new network solution for all potential participants in order to model the choice behavior between the current situation and the new network solution. This choice behavior can either be deterministic or probabilistic (C).

The fourth step consists of the procedure for the actual design of the network using a search procedure to find a feasible hub network. Every time an alteration is made to the network the implications of this new network solution on the use of the network is calculated followed by: (1) the transaction costs (δ_i^{tc}), (2) the resistance (ϵ_i^s), (3) the costs of participation (c_s^{hub}, $\forall i$), and (4) the resulting use (based on the costs) of the new network solution again needs to be calculated (step 5 in Figure 7-1). This is an iterative process resulting in the use of the network solution, the transaction costs (δ_i^{tc}), and the resistance (ϵ_i^s) per individual participant. For this search procedure the simulated annealing methodology was used. Once the criteria are met, or a stable solution is found the network is evaluated using the simulation module (6), for example the maximum number of iterations is reached or the improvement solution *n* and *n+1* is smaller than the predefined criteria. In this module the solution is tested and validated to assess the reliability, robustness and cost-effectiveness of the network solution based on actual order-information.

Finally in step 7 the network is implemented. This step is outside the scope of this research though it is crucial to mention this phase as our objective is to find a feasible network solution but we also want to find a feasible network development, which is used during the implementation. The design and evaluation framework was developed to support the implementation process of collaborative logistics networks, and although the focus of the dissertation is on the design and evaluation using different modeling techniques, the capability to delineate the development path of these networks, implement different scenarios, and assess their feasibility is an indispensable part of the research. We therefore focus on finding feasible networks and less on finding the optimal network configuration. To be able to give the successive development of these networks, additional complexity is added, which made it necessary to make concessions on the performance in terms of finding the optimal solution.

7.2 The objective and design variables

In the previous section the seven steps of the comprehensive network design methodology were presented. One key element in this approach is the network design step in which the system costs and logistics of the participants are minimized, the participants collaborate and the decision to participate is based on the costs of the current situation and the new network solution, including the transaction costs and additional resistance. The question to be solved is what is a feasible hub network solution in which the total costs are minimized, given the costs of the current network, the transaction costs, and the additional resistance to participate?

To address this question we first make use of the standard formulation of a hub network problem, after discussing the specific design issues we need to address. Our approach differs from most hub network design models as we not only focus on the feasibility of the final network solution but are also interested in the development path towards this network. We also incorporated restrictions on the path towards this final network solution in terms of the initial cost reduction, the capacity available and the admittance of a new participants by the consortium. The underlying design problem can be formulated as a standard hub network problem in which the total logistics costs and transaction costs need to be minimized. In this section we present our formulation of the capacitated multiple allocation hub location problem. In this formulation there is also cost associated with the establishment of a hub. Consequently, the number of hubs for any given problem needs to be derived by the mathematical decision model. In Ebery *et al.* (2000) a capacity restriction is placed on the volume of traffic entering the hub via collection. In our version of the model we introduce capacity restrictions on the flow entering and leaving the hub and on the inter-hub flow. In the list below the different types of variables are listed. The key design variables are the opening of the hubs, the sequences, the capacity of the hubs and sequences, and direct/hub shipments. In addition, the endogenous and exogenous variables are presented.

Design variables

- opening hubs — the number of hubs and locations of the hubs
- sequences — the inter-hub services connecting the hubs
- capacity of the hubs — transshipment capacity in loading units/time unit
- capacity of the sequences — the capacity deployed on the inter-hub services
- direct/hub shipment — the choice between direct and the hub-network
- participants — the actors joining the consortium

Endogenous variables

- integral costs/item — total cost (transport, handling, transaction costs, etc.)
- lead-time — total shipment time between origin and destination
- utilization of assets — the utilization of vehicles, equipment and assets
- direct/hub shipment — fraction of the flow sent directly or via hub-network
- choice to participate — the decision to participate in the collaboration

Exogenenous variables

- potential participants — the individual actors that can join the consortium
- type of collaboration — type I, II, and III
- potential hub locations — the nodes where a hub can be located
- transport rate road transport — labor costs/hour, fuel costs, etc.
- hub-network investments — investment in equipment, information technology,etc.
- transaction cost characteristics — frequency, distribution of the asset specificity
- additional resistance — additional costs incurred based on the collaboration
- network characteristics — the network description, nodes, links, type, etc.
- facility costs — investment costs in cost/m2
- transshipment characteristics — technique and capacity on the hub
- product characteristics — value, volume, weight, loading unit

Before we present our model formulation we first provide an formulation excluding the transaction costs and additional resistance an actor might have. This formulation (7.1) will then be extended.

Let us define the graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ where $\mathcal{V} = \{1,...,v,...,|\mathcal{V}|\}$ is the node set of all origin and destination nodes. $\mathcal{E} = \mathcal{V}^2$ is the set of directed arcs and the set of potential hub nodes is $\mathcal{K} \subseteq \mathcal{E}$. The set of origin-destination pairs (OD) is $\mathcal{W} \subseteq \mathcal{V}^2$ and we consider a situation in which there are $\mathcal{I} = (1,...,i,...,|\mathcal{I}|)$ origins and $\mathcal{J}$ destinations indexed $\mathcal{J} = (1,..., j,...,|\mathcal{J}|)$ The volume on origin-destination pair (ij) is denoted d_{ij} . We do not assume that $d_{ij} = d_{ji}$. The cost of shipping d_{ij} units directly form origin i to destination j is denoted c_{ij} and is usually proportional to the distance between origin i and destination j . Generally these distances are Euclidean, in our formulation we use network based distances and the travel-times on these same origin-destination relations. Each flow shipped through the hub network has three separate distance related components: *collection* (origin node-to-hub), *transfer* (inter-hub), and *distribution* (hub-to-destination node). Note that the inter-hub distance can be equal to zero in a 1-hub network. So as an alternative to direct *origin node-to destination-node* shipment there are $\mathcal{K} = (1,...,k,...,|\mathcal{K}|)$ possible hubs of which $\mathcal{S} = (1,...,s,...,|\mathcal{S}|)$ sequences can be made from the access-hub k near the origin (i) to the egress-hub l , $\mathcal{L} = (1,...,l,...,|\mathcal{L}|)$ near the destination (j), $\mathcal{L} = \mathcal{K}$. Let $s \subset \mathcal{K}$ denote a sequence of hubs $\mathcal{K}$. Sequence s consists of one or more segments *a,* and each sequence s consists of one or more hubs k. Each participant is denoted by its unique index i. The cost per unit flow for collection is denoted c_{ik} , for the transfer c_s^{hub} and distribution c_{lj} . In our problem formulation these costs are dependent of the flow and thus dependent of the decision variables (X_{ij} , X_{ijkl} , and Y_k). In turn, the decision to participate (captured by the decision variable) is determined by the costs. In our problem formulation we use the notation $c_{ik}(X)$, $c_s^{hub}(X)$, and $c_{lj}(X)$ to indicate that the costs (c_{ik} , c_s^{hub} and c_{lj}) are a function of the decision variables, denoted by X without subscript. The number of hubs open on a sequence s is given by the cardinality of the set $\mathcal{K}$. Paths in the graph are identified as a sequence of the nodes traversed.

In the network design optimization model below (7.1-7.12) the decision variable X_{ijkl} denotes the fraction of flow that travels from node i to j via hubs located at k and l , the decision-variable X_{ij} denotes the fraction of flow from node i to j that is shipped directly ($X_{ijkl} + X_{ij} = 1$),the variable X_i , $\forall i \in \mathcal{I}$ is defined by $X_i = 1$ if a fraction of the flow of participant i is shipped via the hub network and $X_i = 0$, if otherwise, the decision-variable Y_k , $\forall k \in \mathcal{V}$ is defined by $Y_k = 1$ if node k is a hub and $Y_k = 0$ otherwise. F_k is the fixed cost associated with the establishment of a hub at node k and χ_k is its capacity. The decision variable Z_s , $\forall s \in \mathcal{S}$ is defined by $Z_s = 1$ if sequence s is present in the network and $Z_s = 0$ otherwise. ϕ_s is the capacity on sequence s .

In the formulation (7.1) we present the hub network design formulation with fixed costs and capacity restriction on both the hubs and inter-hub transfer services. The first term represents the costs of shipping directly between origin and destination. The second terms represents the costs of collection when shipping through the hub network. The third term $c_s^{hub}(X)$ represents the total costs of the interhub-transfer. Note that these costs depend on the decision variables. The fourth term in our formulation represents the distribution costs (from the hub to the final destination). The final term in this formulation represents the costs of opening a hub in the network and incurres the associated fixed costs. Conservation equations (7.2) ensure that the total flow (d_{ij}) from i to j is transferred either through the hub network or using direct shipment from i to j , while equations (7.3) and (7.4) guarantee that transfers only occur via valid hubs.

These equations (7.2)-(7.4) ensure that the total demand is sent through the network. Equation (7.5) ensures that the capacities on the hubs are being adhered to. Equation (7.6) ensures that the capacity on the sequences connecting the hubs is adhered to. Restrictions (7.7)-(7.12) define the decision variables.

$$\begin{aligned}&\min_{x,z} F(x,z) = \\ &\sum_{i\in\mathcal{I}}\sum_{j\in\mathcal{I}}\sum_{k\in\mathcal{K}}\sum_{l\in\mathcal{L}}\Big(\big(c_{ij}(X)d_{ij}(1-X_{ijkl})\big)+(c_{ik}(X)+c_s^{hub}(X)+c_{lj}(X))d_{ij}X_{ijkl}\Big) \\ &+\sum_{k\in K}(F_k)Y_k\end{aligned} \tag{7.1}$$

Subject to:

$$X_{ij}+\sum_{k\in\mathcal{K}}\sum_{l\in\mathcal{L}}X_{ijkl}=1 \qquad \forall i,j\in\mathcal{V} \tag{7.2}$$

$$\sum_{l\in\mathcal{L}}X_{ijkl}\le Y_k \qquad \forall i,j,k\in\mathcal{V} \tag{7.3}$$

$$\sum_{k\in\mathcal{K}}X_{ijkl}\le Y_l \qquad \forall i,j,k\in\mathcal{V} \tag{7.4}$$

$$\sum_{i\in\mathcal{I}}\sum_{j\in\mathcal{J}}d_{ij}\sum_{l\in\mathcal{L}}X_{ijkl}\le \chi_k Y_k \qquad \forall k\in\mathcal{V} \tag{7.5}$$

$$\sum_{i\in\mathcal{I}}\sum_{j\in\mathcal{J}}d_{ij}\sum_{k\in\mathcal{K}}\sum_{l\in\mathcal{L}}X_{ijkl}\le \phi_s Z_s \qquad \forall s\in\mathcal{S} \tag{7.6}$$

$$Y_k\in\{0,1\} \tag{7.7}$$

$$X_i\in\{0,1\} \tag{7.8}$$

$$Z_S\in\{0,1\} \tag{7.9}$$

$$0\le X_{ijkl}\le 1 \tag{7.10}$$

$$\sum_{k\in\mathcal{K}}\sum_{l\in\mathcal{L}}X_{ijkl}\le 1 \tag{7.11}$$

$$0\le X_{ij}\le 1 \tag{7.12}$$

With this model, the hubs are capacitated and there is a fixed cost associated with establishing a given node as a hub. Next to the capacity restriction on the hubs we introduce capacity restrictions on the inter-hub connections. In order to take into account the cost reductions that are obtained by consolidation at hub nodes, the technique used in the standard linear hub-location model has been to apply a so-called discount factor on the inter-hub links of the network, so that the per-unit price on inter-hub links is lower than that on external links of the network[16]. It is clear, however, that the use of a linear cost function does not model scale economies, which requires that the marginal price decreases with increasing flow, in which case the cost function must be strictly concave increasing, rather than linear. Clearly, this simplification is costly in terms of accuracy of the solution since large and small flow values all receive the same discount. We explicitly incorporate economies of scale in our cost-functions (c_{ij}, c_{ik}, c_s^{hub}, and c_{lj}). Next to the minimization problem stated in formulation (7.1), we introduce the transaction costs and additional resistance. The decision-variables are identical to the ones in formulation (7.1). We introduce transaction costs and additional resistances. Formulation (7.13) can be derived, subjected to the same restrictions (7.2)-(7.12).

$$\min_{x,z} F(x,z) =$$

$$\sum_{i\in\mathcal{I}}\sum_{j\in\mathcal{I}}\sum_{k\in\mathcal{K}}\sum_{l\in\mathcal{L}}\Big(\big(c_{ij}(X)d_{ij}(1-X_{ijkl})\big)+(c_{ik}(X)+c_s^{hub}(X)+c_{lj}(X))d_{ij}X_{ijkl}\Big) \tag{7.13}$$

$$+\sum_{k\in\mathcal{K}}(F_k)Y_k+\sum_{i\in\mathcal{I}}(\delta_i^{tc}+\epsilon_i^{s})X_i$$

In our formulation the different sequences between the hub pairs can have different cost characteristics per sequence due to the utilization of the assets deployed on the sequence. Consequently, these costs are derived individually and do not depend upon the calculation of the other inter-hub costs, except when two sequences make use of the same hub. As we are in search of a feasible development path that starts with, for example, two hubs and can be extended it is important to calculate the actual discount based on the use of the sequence between the hubs[17]. Therefore, whenever a new development step is implemented, e.g. adding capacity or extending sequences, the use of this new sequence s' is calculated in order to derive the cost/unit. In chapter 6 the conceptual framework was presented and the importance of the transaction costs (δ_i^{tc}) and additional resistance (ϵ_i^{s}) to participate was discussed. In order to implement the effects of these factors on the network design and development path of the network, we introduce the hub design formulation including δ_i^{tc} and ϵ_i^{s} presented in formula (7.13). In this formulation the costs of participating are incurred if $X_i = 1$, if potential participant i does not join the collaborative hub network $X_i = 0$. Before we present the solution procedure and illustrate this procedure we will first discuss the implemented cost functions in the following section. Based on the distinct network activities we will illustrate the adopted cost formulas to derive the unit costs. We illustrate both alternatives, namely the cost calculation of the starting situation of the potential participants, in this case direct road transport, and the cost calculation of shipment the using the hub-network.

7.3 The cost functions

In the previous section we mentioned the inherent complexity of our design problem and the dependency between the use of the network solution and the costs of using the network solution: the use of the network is determined by the costs and the costs are determined by the use of the network. This is a classical equilibrium problem, referred to as a MPEC

[16] See, for example, Ernst and Krishnamoorthy (1998) or Hamacher *et al*. (2000).

[17] See Figure 5-6 in which the costs per shipment are based on the flow and shipment size between origin and destination.

problem (Mathematical Program with Equilibrium Constraints). In our formulation the costs of direct shipment, collection, transfer, distribution and handling are dependent of flow ($c_{ij}(X)$, $c_{ik}(X)$, $c_s^{hub}(X)$, and $c_{lj}(X)$. However, the introduced transaction costs and additional resistance are also determined by the use of the network, and thus $\delta_i^{tc}(X)$ and ϵ_i^s (X). To illustrate the cost functions and the methodology to introduce economies of scale into the cost calculation we will discuss the costs incurred for *motion*, *holding*, *handling*, *administration*, and the newly introduced category, referred to as *switching*.

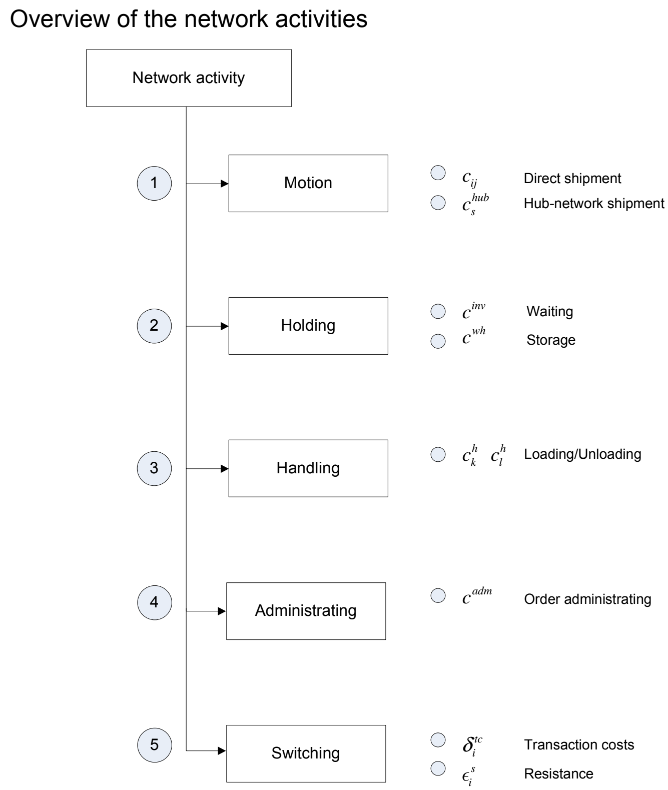

Figure 7-2: Network activities and the accompanying costs

Each category will be illustrated by one or more examples. We will discuss the costs incurred for direct shipment (c_{ij}); hub network shipment (c_s^{hub}); waiting (c^{inv}) and storage costs (c^{st}); handling costs at the hubs (c_k^h); administrating costs (c^{adm}); and finally the transaction costs (δ_i^{tc}) and additional resistances (ϵ_i^s). Figure 7-2 depicts the different categories and the related cost components we will present in this section. The cost functions presented and discussed are merely presented to illustrate the methodology of cost calculation and assignment. In addition, the level of detail that is incorporated in the optimization model, discussed in the previous section is illustrated. The notation is consistent with the previous chapters and can be found in the *Glossary of mathematical symbols* on page xii.

Direct shipment

We start with the costs incurred for sending a shipment directly from an origin to a destination. These costs of direct transportation[18] comprise the fixed costs per shipment (investment, insurance, depreciation, overhead), denoted c^{tf} and the variable cost (labor, fuel, maintenance), denoted $c^{tf} t_{ij}$, in which c^{tf} is the variable cost per time unit per shipment and t_{ij} is the transport time of line haulage between origin *i* and destination *j*. For direct haulage we assume an average shipment size, denoted v^T, in units or loading units per shipment. The maximum shipment or capacity on *ij* is denoted $v^T_{\max}$. The costs of shipping directly from origin *i* to destination *j*, denoted c_{ij} is:

$$c_{ij} = \left(\left(c^{tf} + c^{tv} t_{ij}\right) v^T\right) \Big/ v^T_{\max} \tag{7.14}$$

Hub-network shipment

Similarly the costs for collection from origin i to hub k, denoted c_{ik}, and distribution from hub k to destination j, are calculated using formula (7.14), although the parameters (e.g. c^{tf}, c^{tv}, and $v^T_{\max}$) can be different, yielding different costs per unit. The costs for shipping via the hub network are calculated, referred to as the inter-hub transfer costs. These costs, denoted c_s^{hub}, comprise the fixed costs (c_s^f) per time unit multiplied by the sum of the transport time and handling (T_s), the variable costs per time unit (c_s^v) multiplied by the transport time (t_s), and the utilization of the capacity available on sequence *a* (μ_s)[19].

$$c_s^{hub} = \left(\left(c_s^f T_S + c_s^s t_s\right) \mu_s\right) \tag{7.15}$$

An important determinant of the costs for transportation via the hub network is the utilization factor of the deployed equipment, denoted μ_s, a variable dependent of the capacity that is available on sequence s. The overall utilization of sequence *s* is derived from the used capacity per segment (ϕ_s). For example, let a sequence s consists of 4 segments $s = (a_1, a_2, a_3, a_4)$ with a capacity $\phi_s = 1000$. Segment a_2, a_3, and a_4 are completely filled, while the capacity on segment a_1 is only 75% utilized. Let all segments be of the same length and transshipment times on all hubs are equal ($t_1 = t_2 = t_3 = t_4$). The number of units on segments a of sequence s are denoted $d_{a,s}$. Utilization factor is calculated as follows:

$$\mu_s = \sum_{a \in s} (t_s d_{a,s}) / \sum_{a \in s} (t_s) . \phi_s \tag{7.16}$$

In our example the utilization factor (time per segment $t_1 = 1$), is thus: $\left(\left(1 \cdot 750\right) + 3 \cdot \left(1 \cdot 1000\right)\right) / \left(4 \cdot 1000\right) = 0.94$. The total capacity of the sequences can be derived from the cycle time of the sequence, (t^{cycle}). This is the total inter-hub transfer time for all segments on s and the time of handling activities on the hubs.

$$\phi_s = \left(H_s / t_s^{cycle}\right) \cdot v^{hub}_{\max} \tag{7.17}$$

With the cycle time of sequence s it is then possible to derive the maximum numbers of cycles/time unit, e.g. the number of cycles/year. Let H_s denote the available operational

[18] These costs are usually the costs for the current network solution (depicted step 2 in Figure 7-1).

[19] This is essentially our implementation of the economies of scale where the utilization of the capacity determines the actual *discount* compared to c_{ij}

hours/year, then with the capacity $V_{\max}^{hub}$ in units per vehicle (or vessel) the maximum capacity in units per year (ϕ_s) can be formulated as in (7.17).

Inventory costs

Inventory costs may be incurred using a relative simple formulation in which the total shipment time from the origin i to destination j is used. Combined with the current interest rate (ρ) and the value of the product (π), the inventory costs are calculated.

$$c^{inv} = \left(\left(t^{cycle} + t_{ijkl}\right) \cdot \pi\rho\right) \tag{7.18}$$

The term in brackets denotes the total shipment and waiting time between production and consumption. Because the expressions implicitly value all the item-hours equally, caution must be exercised when the penalty depends on the time of day, week or year when this wait occurs. In section 5.2 we discussed a similar formula, where in equation (5.2) only the maximum interval (or headway) between successive dispatches, $H_1 = \max\{H_w\}$ was used, whereas in equation (7.16) we refer to the interval between dispatches as the cycle-time, denoted t^{cycle} .

Warehousing costs

In addition to the costs incurred for inventory we distinguish the warehousing costs or facility costs, denoted c^{wh} . These costs depend on the size of the items, the volume or throughput of the facility, their storage requirements and the prevailing rents for space. Below we simplify this by formulating the warehousing costs (€/item), denoted c^{wh} , as follows:

$$c^{wh} = \left(\left(C_k^{whl} + C_k^{whf} + C_k^{whf}\right) / Q_k\right) \tag{7.19}$$

We distinguish the annual labor costs, denoted C^{whl} , the annual costs of the investment in storage space, denoted C^{whf} and the costs in €/year incurred for the handling equipment, denoted C^{whh} . The sum of these annual costs is then divided by the annual throughput of the warehouse Q_k (items/year). These annual costs are derived from the total investment in the warehouse (footprint, building, offices, etc.), the interest rate, depreciation, and the used depreciation term.

Handling costs

An important cost component of the integral costs of a shipment sent through the hub-network, is made of by the handling costs. The costs for handling on a hub are based on the flow and the characteristics of the specific hubs. Therefore the handling costs c^h are introduced consisting of the costs for handling activities at the *origin* hub (c_k^h) and at the destination (c_l^h). This distinction is made because; (1) different techniques can be used at both hubs, and (2) the costs are based on the total throughput volume on the hub, and therefore different capacities and costs for handling at both hubs can exist. In other words: the cost functions for handling on the hub are responsive to flow.

$$c^h = c_k^h + c_l^h \tag{7.20}$$

Here we illustrate the costs for handling at a single hub k of a sequence s. The cost function consists of the annual fixed costs for the equipment at the hub, denoted c_k^{hf} , and the annual labor costs, denoted C_k^{hl} .

These costs are then divided by the total throughput on the hub (Q_k). Note that the throughput Q_k is the sum of all shipments handled at the hub, not just the shipments that go through the hub of sequence s (see formula 7.22, in which all shipments are summed over all sequences using the hub).

$$c_k^h = \left(\left(C_k^{hf} + C_k^{hl} \right) \middle/ Q_k \right) \tag{7.21}$$

$$Q_k = \sum_{s=1}^{S} (Q_{k,s}^{in} + Q_{k,s}^{out}) \tag{7.22}$$

Next we introduce the utilization factor of the handling equipment at the hub, denoted μ_k^h. This factor is calculated by dividing the throughput Q_k by the capacity of the equipment at the hub (η_k^h) in items/time unit. Dividing this factor by the total available operational time at the hub for handling (H_k^h) the utilization can be derived. If the utilization exceeds 1, than additional handling equipment and labor is needed at the hub and the fixed costs C_k^{hf}, C_k^{hl} and capacity η_k^h will increase to the extent that $\mu_k^h < 1$;

$$\mu_k^h = \left(Q_k / \eta_k^h \right) \middle/ H_k^h \tag{7.23}$$

The utilization factor of the equipment on the hub is calculated as a check to be sure that capacity is not exceeded and if so additional equipment needs to be installed at the hub.

Administrating costs

In our cost calculation we explicitly incorporate costs for administration of the orders. Due to the fact that, in complex networks, the interaction between actors and the information flows can be substantial, considerable costs can result for administration. In expression (7.24) the administration cost per item is presented, derived from the costs per order (c^{ord}) and the average order size ($\bar{\varpi}$).

$$c^{adm} = c^{ord} \middle/ \bar{\varpi} \tag{7.24}$$

The costs for the order administration, planning and processing is based on the investments for the information technology (C^{is}), the depreciation period ($\dot{t}^{is}$), and interest rate (ρ). Next the number of employees needed (*FTE*) and annual labor cost per employee (C^{isl}) are introduced. Finally the total number of orders processed (*O*) is used to derive the costs per order.

$$c^{ord} = \left(\left(\left(C^{is} / \dot{t}^{is} \right) + C^{is} \rho \right) + FTE \cdot C^{isl} \right) \middle/ O \tag{7.25}$$

The different types of collaboration require different governance structures and information systems to accommodate the orders, information and product flows so the order costs are dependent of the type of collaboration and the governance structure.

Switching costs

Finally, the transaction costs and additional resistance are distinguished in formulation (7.13). These transaction costs can emerge in all phases of the decision-making process to participate. In accordance with the discussion on transaction costs in Chapter 3 we distinguish two primary categories: (I) costs caused by information problems, search and information costs, bargaining and enforcement costs; and (II) the consequential costs arising from the strategic exercise of information asymmetry by the informed party, opportunity costs.

$$\delta_i^{tc} = \delta_i^{tcI} + \delta_i^{tcII} \tag{7.26}$$

The first category (I) transaction costs can be further broken down into three components: search costs (c^{sc}), bargaining costs (c^{bc}), and enforcement costs (c^{ec}).

$$\delta^{tcI} = \left(c^{sc} + c^{bc} + c^{ec}\right) \tag{7.27}$$

An example of search costs (c^{sc}) is provided by the number of employees involved (*FTE*) in searching for information, and the (C^{scl}). In addition, lump-sum costs can be incurred due to consultancy or legal fees (c^{scf}).

$$c^{sc} = \left(FTE \cdot C^{csl}\right) + c^{csf} \qquad \text{(7.28}$$

The opportunity costs δ^{tcII} are based on three cost components that can be present when a transaction takes place. If opportunistic behavior arises a hold-up offer could be offered resulting in an additional payment of ΔB and/or value loss due to inferior quality $f^{l}(\Delta Q)$. The extra legal and arbitration costs are then introduced (c^{leg}).

$$\delta^{tcII} = \Delta B + f^{l}(\Delta Q) + c^{leg} \tag{7.29}$$

The costs presented in the expressions (7.26-7.29) are dependent of the type of collaboration, especially the distribution of the costs over the different participants depends on the type of collaboration and its characteristics.

7.4 Solution procedure

In the previous section we presented the model structure, the formulation of the design problem and presented the underlying cost functions. The number of decision-variables in our formulations is large, and the combinatorial complexity is enormous. Solving these types of problems exactly is not feasible. However, in our approach it is not a necessity. In general three approaches are proposed to handle the mathematical complexity. The first approach is to adopt a partial approach, whereby some aspects are simplified for mathematical convenience. The second is to find a way to separate the problem into convenient sub-problems. Finally, the third approach is to recognize the inherent mathematical difficulty, and seek a local rather than a global optimum (O'Kelly and Miller 1994; Current *et al.* 2002).[20]

The approach we propose here is an exponent of the latter, where we seek a feasible network solution and hereby accepting that this could well be a local optimum rather than a global. To search for a feasible solution we have used *Simulated Annealing*[21], a heuristic methodology used for a variety of optimization problems. In order to assess the heuristic we

[20] See for examples of these approaches section 5.4.4 on the different solution procedures used for complex hub network design problems.

[21] Simulated Annealing is an artificial intelligence technique and is often referred to as one of the five artificial intelligence techniques to solve complex problems. The other four are *Genetic Algorithms*, *Neural Networks*, *Tabu Search*, and *Target Analysis* (Abdinnour-Helm, 2000).

have tested the algorithm on several benchmark problems available in literature. We tested the simulated annealing procedure on a set of small and large sized problems and evaluated the performance of the Simulated Annealing using the performance of several other solution procedures (*Tabu search*, *Branch and Bound*, an exact algorithm, and two additional heuristics)[22].

7.4.1 Simulated Annealing

With the simulated annealing approach applied to the design of a hub network, a feasible solution corresponds to a set of hubs with all other nodes assigned to one of the hubs. The cost of this feasible solution is the sum of the transportation costs on the hub-to-hub links and the hub-to-spoke links. The temperature parameter of simulated annealing is a function of the acceptable cost difference between two feasible solutions (p-hubs, all nodes assigned to a single hub and all hubs inter-connected). When simulated annealing is started, a considerable cost difference is generally accepted but, as the number of iterations increases, a smaller cost difference is accepted. This temperature analogy allows simulated annealing to accept a worse feasible solution in the hope of arriving at a better solution (lower total logistic cost). In the examples above a relatively simple SA algorithm was used. To be able to use SA for the design of hub networks some modifications need to be made to the algorithm. Based on Abdinnour-Helm (2000) we present the formulation below.

For a given annealing schedule of temperatures, $\{\tau_0, \tau_1, ..., \tau_f\}$ an initial temperature τ_0 is calculated, i.e. $e^{-\Delta C/\tau_0} \cong 1$, where ΔC is the cost difference between two network solutions. The temperature τ is decreased using the rule: $\tau = \alpha\tau$, $\alpha = (0 < \alpha < 1)$. The maximum number of iterations at each τ, referred to as the length of the *Markov Chains,* is denoted (L). The final Temperature (τ_f) is the zero temperature level. The procedure will be stopped when τ_f is reached, or earlier if the procedure seems to be converging to a value that has not changed over a large number of iterations. The above cooling schedule has been widely used and found effective on several problems. The SA algorithm used to solve p-hub problem is depicted in Figure 7-3[23].

The algorithm starts with the calculation of the initial temperature and initializing the *Best Solution* This means determining the length of the *Markov Chains,* (L), the maximum number of assignments made to a hub in the initial solution, the number of iterations for exchanging a hub , and the discount factor for the initial temperature τ_0. Then *p* is randomly chosen and each of the remaining *n-p* nodes are assigned to the closest hub. Then the annealing procedure starts and a neighbor solution is generated, and, based on the cost difference between this solution and the previous network solution it is decided if the current solution becomes the *Best Solution.* During the annealing procedure a random number, that is uniformly distributed, is generated ($0 < \xi < 1$). The next step is then to calculate the acceptance probability, where $\text{Prob}^{ac} = e^{-\Delta C/\tau_0}$, and if $\xi < \text{Prob}^{ac}$ then the New Solution is set to the *Parent Solution*, otherwise the current solution is retained.

[22] The result of these tests can be found in Appendix D:Performance of the solution procedure.

[23] See for a description of the heuristic Appendix C: Solution procedure SA with the stepwise approach of this SA algorithm based on Abdinnour-Helm (2000).

Then, based on the cooling schedule[24] that is used, the probability of accepting a solution that yields higher costs as its predecessor decreases. If finally, the maximum number of iterations ($l3 > L$) and the final temperature ($\tau_0 = \tau_f$) is reached the procedure ends.

Schedule of Simulated Annealing algorithm for
Hub network design

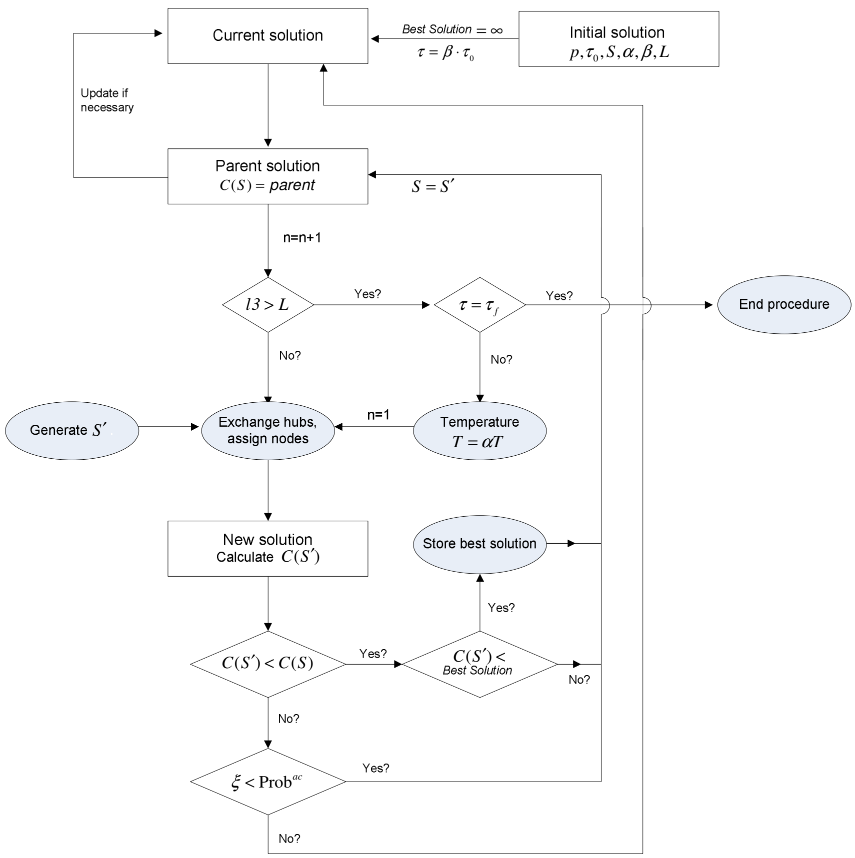

Figure 7-3: Schedule of the Simulated Annealing algorithm for the general hub network design problem (p-hub, SA).

7.4.2 The developed solution procedure

Based on the analysis of the heuristic Simulated Annealing and the results of tests that were performed on several standard problems, using different heuristics we concluded that the performance of SA on hub network design problems is excellent in terms of finding the global optimum and CPU time to attain the solution. Next we extended this standard SA algorithm and implemented additional steps that make it possible to design a collaborative network and

[24] See Appendix B: Cooling Schedules for different well-known cooling schedules.

not only find a feasible network solution but also illustrate the network development path. In addition we include the transaction costs and additional resistance that firms have in joining a alternative network solution. By doing this we introduce additional complexity that demands additional capacity on the solution methodology. But thanks to the flexibility and robustness of the SA algorithm it was possible to incorporate these additional variables into the design problem and still make use of the powerful search procedure of SA. In this section we will illustrate the adaptations and additions made to the standard algorithm. In order to reduce the complexity and combinatorial possibilities we make use of different preprocessing steps that reduce the complexity. These techniques will be discussed in this section. Another reduction is made by the restrictions set on the development path of the network solution.

Figure 7-4 presents the schedule of the extended simulated annealing algorithm. In this figure the additional steps that are included in the methodology are framed by the gray-filled square and referred to as the *Inner optimization and assignment procedure*. The remaining steps and relations are roughly in accordance to the schedule of the SA algorithm presented in Figure 7-3. Note that the calculation of the use of the hub network (VII) is detailed further in Figure 7-5 (the additional notes depicted in both figures Figure 7-4 and Figure 7-5 are subjoined to Figure 7-5).

The search procedure starts with the preprocessing and initialization process (I). Firstly, a potential savings matrix is generated, denoted (ΔM). In this matrix the potential cost savings for all origin and destination relations are listed. It is assumed that for all relations $i \to j$ a hub k is located at the nearest potential hub location ($k \in \mathcal{K}$) minimizing c_{ik} , and hub l is located at the nearest hub location $l \in \mathcal{L}$, minimizing c_{lj} and for sequence $s = \langle k_1, k_2, k_1 \rangle$ the shortest path between $k_1 \to k_2$, and $k_2 \to k_1$ is used. It is assumed that $\mu_s = 1$; $\mu_k^h = \mu_l^h = 1$; $\delta_i^{tc} = 0$; and $\epsilon_i^s = 0$ ($\forall i$),yielding the minimum possible costs for joining the hub network solution ($\forall i \to j$). Then, using the difference between the current situation and the situation in which the network is joined, Δm_{ij} is derived, denoting the potential cost difference to a hub network solution in its best possible configuration $\forall i \to j$ individual. This matrix ΔM then indicates the possible reductions and for those relations on which $\Delta m_{ij} \le 0$ it indicates that a hub network, even in its most positive form for all the participants individually, it is no feasible alternative. In addition, this matrix can be used to determine the search directions when adding or inserting a hub to the sequences.

The SA procedure starts with an initial solution (denoted II in Figure 7-4) consisting of a number of starting sequences, the number of hubs within these sequences, the capacity available and the restrictions that are placed on the development path of the network solution. Then in accordance to the SA schedule presented earlier, the *Best solution* $= \infty$, τ_0 is calculated. At the start of the inner optimization the *Parent solution* is saved. Then the adjustments to this solution are made (denoted III in Figure 7-4).

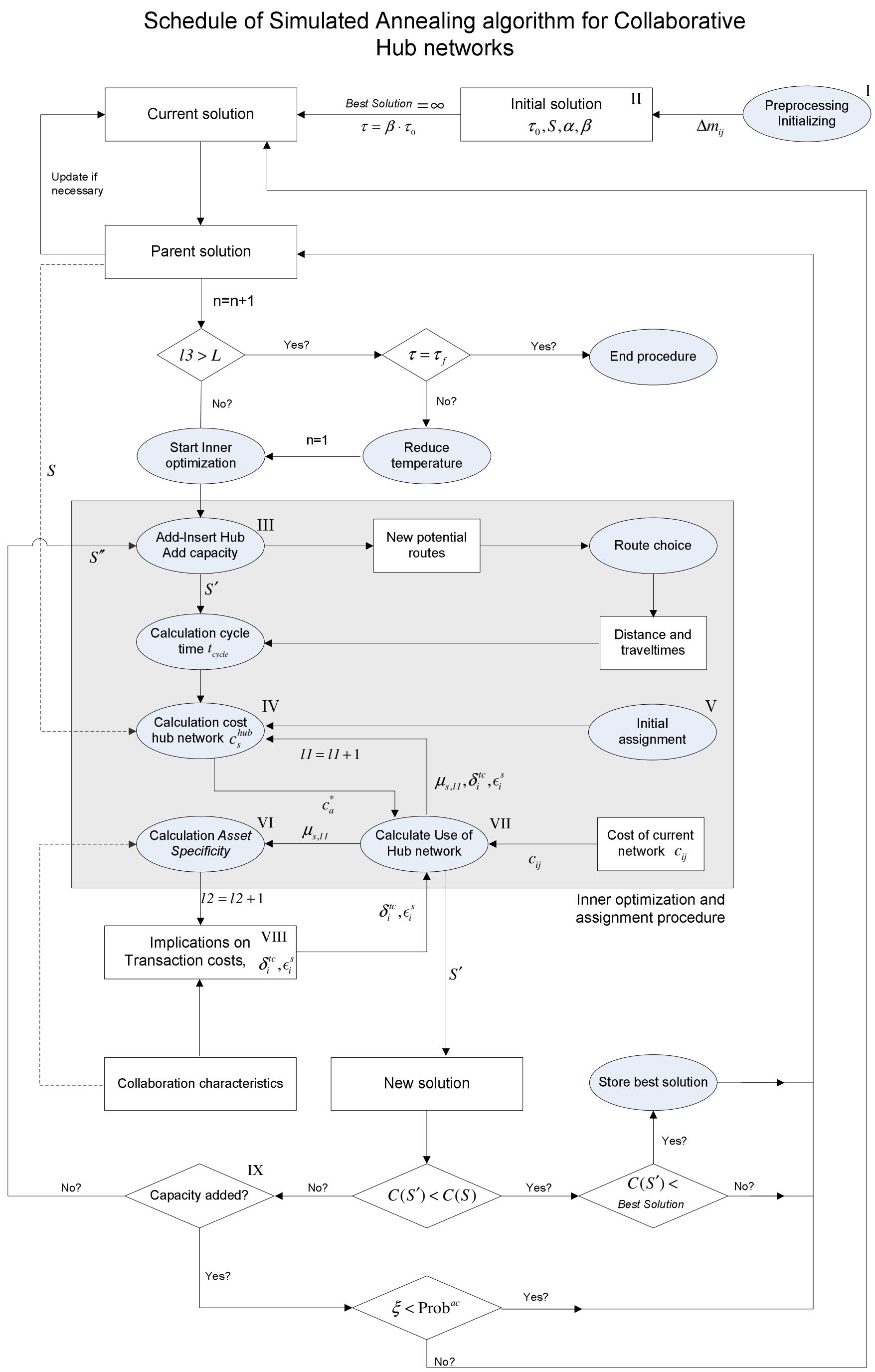

Figure 7-4: Schedule of the extended simulated annealing algorithm.

There are basically two strategies that are used to make the adjustment to the *Parent solution* (S'). The first is adding a hub to the sequence. For example by adding a hub to the sequence $s = \langle k_1, k_2, k_3 \rangle$, would become in $s' = \langle k_1, k_2, k_3, k_4 \rangle$. The second strategy is to insert a hub in the existing sequence. For example $s = \langle k_1, k_2, k_3 \rangle$ becomes $s'' = \langle k_1, k_4, k_2, k_3 \rangle$. Determining the hub to add or insert can be done using the matrix (ΔM) or randomly. To add or insert is decided based on the potential savings matrix, so if $\Delta m^{ins} > \Delta m^{add}$, the *hub-insert* is accepted. If $\Delta m^{ins} < \Delta m^{add}$ the *hub-add* is accepted. The decision to accept the random hub-exchange is made based on the inner search strategy.

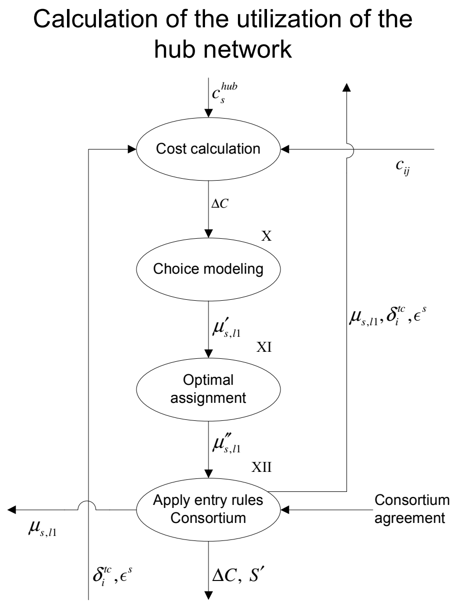

Figure 7-5: Structure of the calculation of the use of the hub network solution

I) Preprocessing step of the search procedure yielding the potential cost savings matrix (ΔM).
II) The initial solution S_0 based on the potential savings matrix ΔM or randomly generated.
III) Several alternative strategies can be adopted to adjust the *Parent solution*. Here we use add, insert or randomly exchange hubs with non-hubs.
IV) This cost calculation is based on formula (7.13)
V) Assignment by prioritizing the capacity based on added value of the individual potential participant.
VI) Using $\mu_{s,l1}$ the utilization of S' at iteration *r*, the asset specificity is calculated, depending on the utilization of the sequence. Whether or not this is the case this depends on the type of collaboration and the contract form that is used in the collaboration.
VII) The use of the network is based on the cost parameters $\delta_i^{tc}, \epsilon_i^s, c_s^{hub}, c_{ij}$, and the choice behavior and consortium settings (see Figure 7-5).
VIII) See formula (7.30).
IX) If S is altered, by adding or inserting a hub and this does not result in an improvement in costs than capacity will be added to see if this will result in an improvement. If this does not help either the solution is either rejected or accepted using the probability Prob^{ac}.
X) Choice modeling using stochastic or deterministic *All-or-Nothing*.
XI) Based on prerequisites on capacity assignment and development of the network.
XII) During the development of the network it is possible to include performance requirements set by the consortium that have to be met if new participants are to join the consortium.

Several inner search strategies were tested; the *Greedy search*, the *Random search* and the *Hybrid search*. In the Greedy search the adjustment with the best potential score, is chosen. This is either the *hub-add* or the *hub-insert* that is selected based on ΔM. The *Random search* selects the hub to add or to insert randomly. The hybrid search selects the *hub-add* or the *hub-insert* based on the performance listed in ΔM , and then randomly decides to use this adjustment or randomly select. This procedure is basically a second SA algorithm, depending on the probability of accepting the randomly selected hub. The trials that were performed showed that the Greedy-search gave the best overall performance in terms of feasible development paths and CPU time. Then if the new solution (S') is generated the new t^{cycle} is derived. To calculate this new cycle time S' and the sequences are to used to calculate the new routes (from and to the hubs and the inter-hub routes) and the travel times and distances.

With the new cycle time of S' the capacity of the sequences can be derived. Next the transaction costs and additional resistance need to be incorporated to be able to calculate the costs of solution S' , and based on the characteristics of the collaboration these costs are calculated. There is however one variable that needs to be derived, and that is the utilization of the sequence ($\mu_{s,l1}$). However, the use of the sequence depends on the costs (c_s^{hub}), and these costs (c_s^{hub}) depend on the utilization of the equipment deployed on the sequence (MPEC problem). This is an iterative process that is either ended when the solution converges and reaches a predefined stopping criterion ($C_{s,l1} - C_{s,l1} < \zeta_s$), or the predefined number of iterations is reached ($l1 > l1_{\max}$). For the initial solution we make use of an initial assignment where all potential participants ($\forall i \to j$) are assigned to the nearest hub if $\Delta m_{ij} > 0$, then if the available capacity is exceeded an initial capacity assignment is generated based on the highest added value of the participant to the performance of the network.

The use of the network solution S' is calculated using the step depicted in Figure 7-5, and yielding $\mu_{s,l1}$. This utilization of the network is then used to calculate the asset specificity and in turn the potential impact on the transaction costs (δ_{tc}^i), and resistance to participate (ϵ_s^i). These two cost components are calculated using the asset specificity and the use of the deployed equipment ($\mu_{s,l1}$). If the transaction costs and resistance to participate are influenced by the use of the assets, and if so a second iterative process needs to converge in order to solve the inner optimization.

If there is convergence ($C_{s,l1} - C_{s,l1} < \zeta_s$), the new solution S' is generated and can be assessed. If the criterion $C(S') < C(S)$ is not met, the capacity of S' is increased resulting in solution S'' . Solution S'' is then sent back into inner optimization. If no improvement is found ($C(S'') < C(S)$) the criterion $\xi < \text{Prob}^{ac}$ is used to decide whether or not the solution S' is accepted and further used for improvement.

In Figure 7-5 the approach used to calculate the use of the hub network solution is depicted. Based on $c_s^{hub}, c_{ij}, \delta_i^{tc}$, and ϵ_i^s , the Δc is calculated and then used in the choice modeling procedure. For this decision we either make use of a *Logit*-model or a deterministic *All-or-Nothing*-model. If for all potential participants it is decided whether or not they participate, the optimal assignment procedure is executed again executed and the potential use of the network solution is then known. However, if applicable, the existing consortium can set restrictions on the participation of new members. For example, every new extension of the network should yield a minimum cost reduction for all members of the consortium of 2%. If this is not the case this extension is rejected by the consortium.

7.5 Testing the methodology on a real problem

In this section we will illustrate the methodology presented in the previous section of this chapter using a data set of a realistic network design problem and present the network solutions and results for different scenarios. For these tests we used the dataset discussed earlier in section 5.5 and section 6.1.3 where we already discussed the final network solution and the development of the network.[25] In this section we will illustrate the impact of different network development strategies and we will discuss the development path of these networks in detail. Next to the final network solution (by a geographical network representation), the development of the network, from the starting solution to the final network, in sequential steps is depicted. In the graphs depicting these paths, the circles denote key extensions. These extensions are either an additional hub that is included in the network or a sequence that is extended. The intermediate steps are iterations of the solution procedure. The vertical axis denotes the total cost decrease. We conclude this section with a tabular overview of the different network design results, with different parameter settings, in terms of type of collaboration, transaction costs, and additional resistances. In addition we included several key indicators of these design runs that indicate the quality of the solution and the performance of the solution procedure.

7.5.1 Collaborative network design

First of all, the network development and network solution is presented when no transaction costs and additional resistances are implemented, referred to as the lower-bound in our analysis. In the second scenario we introduce transaction costs and additional resistance. This development still starts with a cost efficient network solution, without any restrictions to the development path, set by the consortium (see Table 3).

Table 3: scenario variables

	Scenarios			
Variable	1	2	3	4
Start solution	feasible	cost-efficient	random	feasible
Transaction costs	no	yes	no	yes
Additional resistance	no	yes	no	yes
Consortium restrictions	no	no	no	yes

The third scenario is a scenario with no transaction costs but the start solution is randomly chosen. Again, no restrictions are placed on the development path. Finally, we present a scenario in which transaction costs and additional resistances are incurred, a feasible start solution and the consortium introduces restrictions to the development path. For the scenarios in which transaction costs are incurred and collaboration is assumed a type III network collaboration is introduced. This network evolves to a network with 5 hubs in Europe with an annual cost reduction of approximately €25,000,000 (-20.5% cost reduction), that accommodating 78% of all shipments. The jagged pattern of the curve presented in

[25] This set consists of approximately 700 locations (production, warehouse, wholesalers, dealers, and customers) with a total flow between these origin and destinations of 1,578,000 shipments/year and a calculated average of €78.4 / shipment.

Figure 7-6 represents the development steps of the hub network. The key extensions depicted are depicted by either a circle or a square. The circles, denoted H1-H4 in Figure 7-7, indicate the steps in which a hub is added to the network. The circles S1-S4, indicate an additional sequence connection of two or more hubs. Note that adding a hub automatically includes adding at least one sequence.

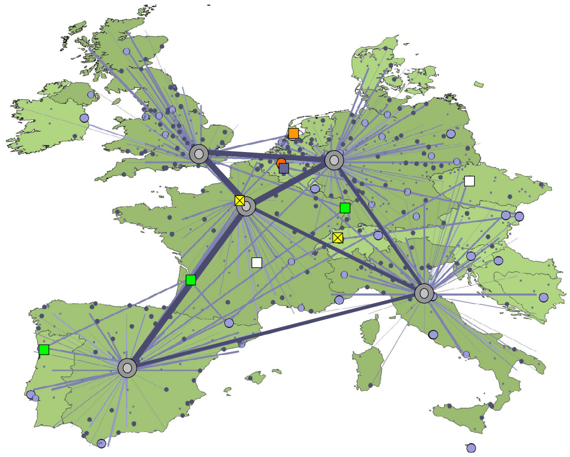

Figure 7-6: **Scenario 1: Feasible starting solution.** Example of the development of the hub network with no transaction costs, no additional resistance to participate and no consortium restrictions.

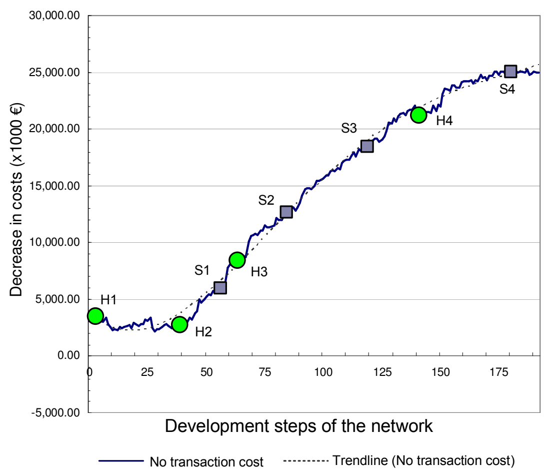

Figure 7-7: **Scenario 1: Feasible starting solution.** Development of the network with no transaction costs incurred.

The steps between the squares and circles are the result of changes in capacity assignment, routing or hub location as a result of the SA-heuristic. Especially in the beginning (the first 50 steps), adding a hub, sequence, locating hubs, assigning capacity, do not always result in a cost reduction. This is because, in the simulated annealing approach, during the beginning of the optimization procedure, a small increase in costs is allowed. Figure 7-6 depicts the result of the lower-bound calculation with a feasible start network (2-hubs and a cost reduction of 2.35%). In total 192 steps are distinguished before no additional extensions are accepted. Figure 7-8 depicts the results of the network design procedure when transaction costs and additional resistance are incurred. In this example the development starts with a feasible network solution and there are no additional requirements set by the consortium.

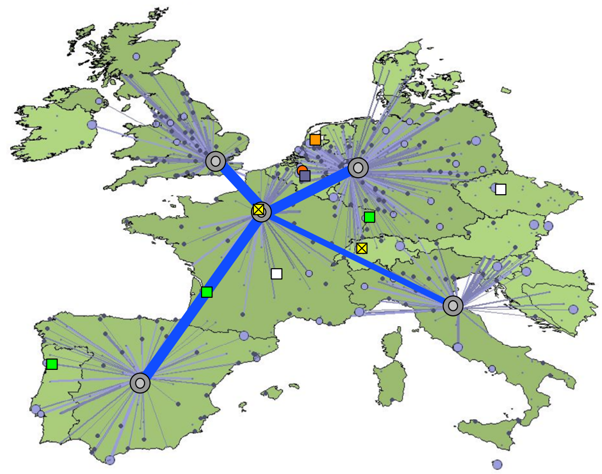

Figure 7-8: : **Scenario 2: Transaction costs.** Example of the development path of the hub network including transaction costs and resistance to participate and no consortium restrictions.

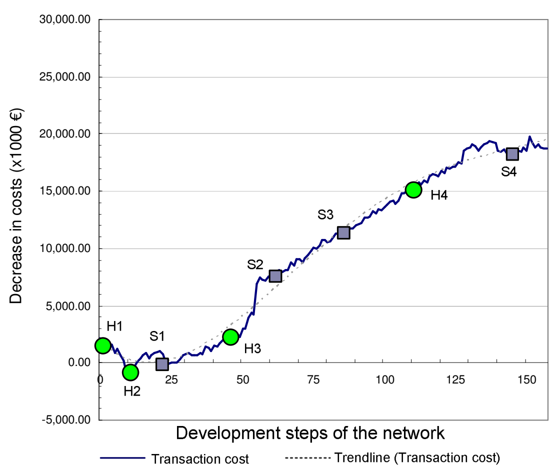

Figure 7-9: **Scenario 2: Transaction costs**. Development path of the hub network including transaction costs and resistance to participate and no consortium restrictions

In total 161 steps are distinguished, yielding a structure similar to the network solution presented in Figure 7-6. However, certain sequences are no longer cost-efficient due to the transaction costs incurred. For certain (potential) participants the hub network is no longer a feasible network solution. The lower-bound calculation yielded a network solution in which the final network solution accommodated 78% of all flows. The network with the transaction costs yielded a result in which 54% of the flows are accommodated. The total reduction in this network solution is € 19,100,000 (-15.6%). A third scenario we discuss is the situation in which the development of the network is started with a random network configuration.

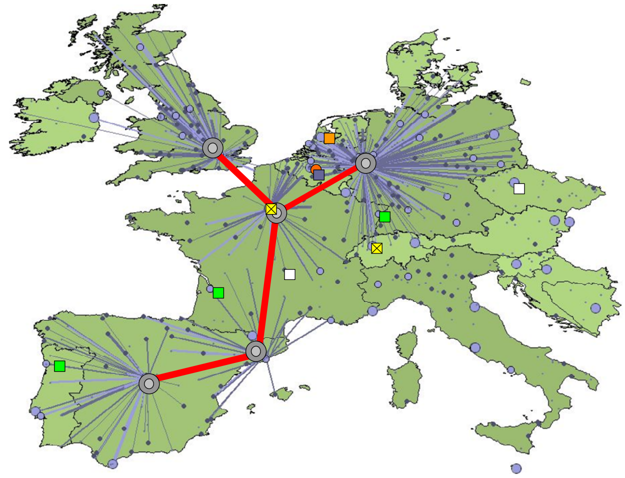

Figure 7-10: **Scenario 3: Random start.** Example of the development path of the network with no restrictions on feasible start solution and consortium settings.

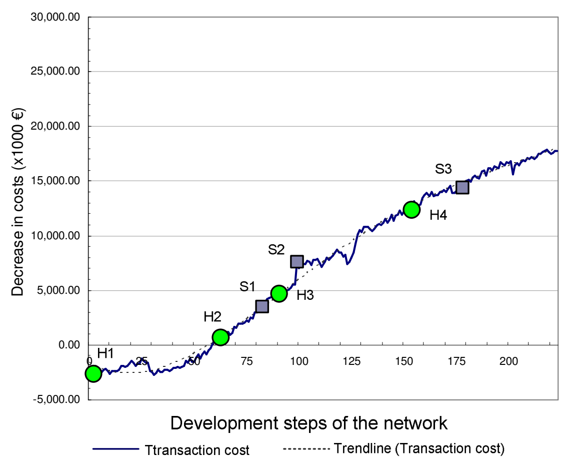

Figure 7-11: **Scenario 3: Random start** . Development path of the network with no restrictions on feasible start solution and consortium settings.

Figure 7-13 depicts the development path of this network scenario, starting with a cost increase of 2.36%, evolving in 253 steps, into a network that yields a cost reduction of €17,900,000 (-14.54%). This is a considerable difference with the lower-bound scenario that is illustrated in Figure 7-6 and Figure 7-7 in terms of total logistics costs and cost reduction that is yielded by the participants that joined this network solution. Additional tests showed that starting the network optimization procedure with a feasible network, based on the potential savings matrix (ΔM), yields better results than starting with a random network. The last example we present in this section is the network development in which the consortium puts restrictions on the network development.[26]

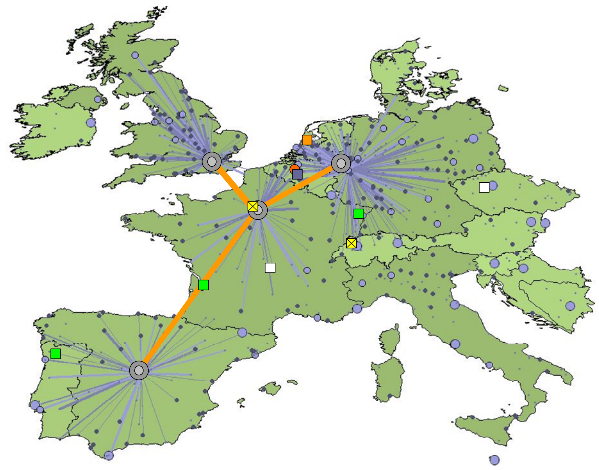

Figure 7-12: **Scenario 4: Consortium restrictions.** Example of the development path of the network with a feasible start, transaction costs, additional resistance, and consortium restrictions.

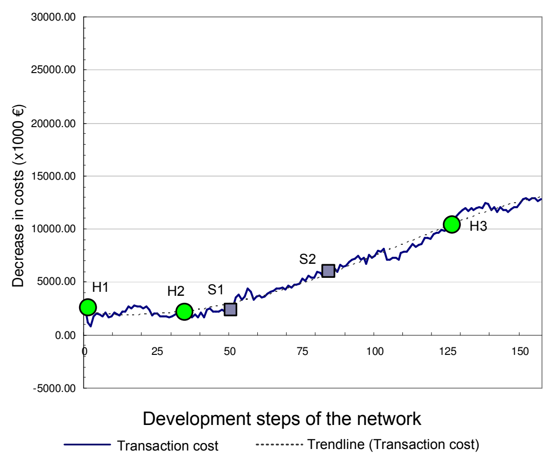

Figure 7-13: **Scenario 4: Consortium restrictions**. Development path of the network with a feasible start, transaction costs, additional resistance, and consortium restrictions.

This development path ends after only 157 steps, compared to the other three scenarios, and results in a network with 4 hubs. A reduction in total costs of €12,900,000 (-10.15%). If we compare scenarios 2 and 4, two scenarios with the same conditions except for the restriction on the development path by the consortium, a difference in cost reduction of €19,100,000-

[26] The consortium in this scenario rejects a network extension if it does not yield an additional cost reduction of 1% of the total cost. The extension is either adding a hub or a sequence.

€12,900,000=€6,200,000 can be observed. This means that when restrictions are included during the network development a considerable reduction in costs is not achieved. This of course is simply an example and we do not want to argue the realism of this example; we simply illustrated the effect such a measure can have on the overall result. It can be observed that, due to this additional restriction, no hub is opened in Italy, as was the case in scenario 2.

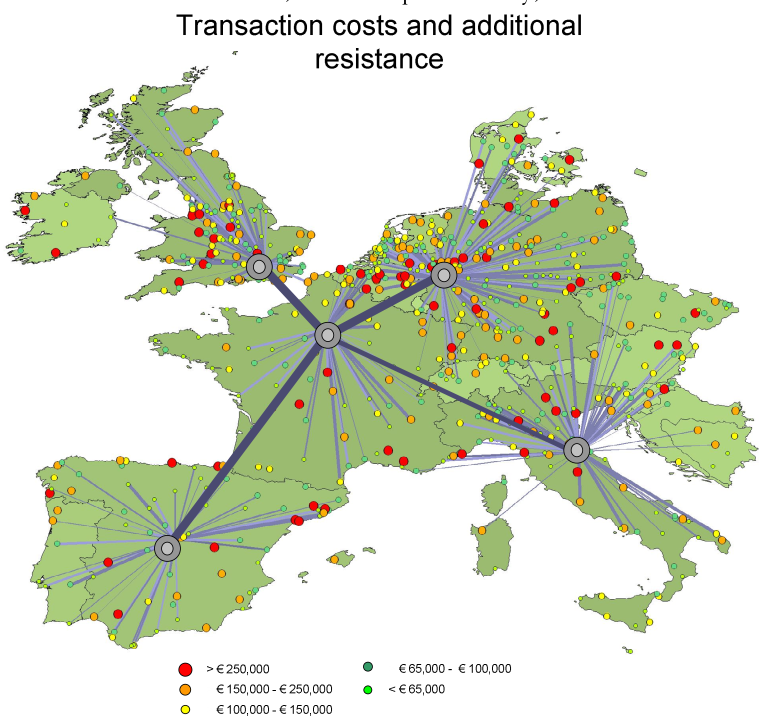

Figure 7-14: Overview of the transaction cost and additional resistance per company and the hub-network participants.

It can thus be concluded that opening a hub in Italy does not result in a sufficient cost decrease for the consortium to admit new participants. Table 4 presents an overview of the results of 6 scenarios. The lower-bound of the European hub-network example is presented first. Next to this scenario, in which no transaction costs are incurred, three types of collaboration are distinguished and two scenarios where the impact of high and low transaction costs are incurred. In this table the different indicators are presented that give an impression of the network design procedure. The first and most important indicator of the network solution is the total costs. As we use a heuristic, and no exact optimization, we calculate a scenario several times to derive the deviation in different solutions. In Table 4 we present the average results based on 20 runs. In addition, the CPU in seconds, the average number of *l1*-iterations (*l1*-loop) and *l2*-iterations (*l2*-loop) is reported. The total steps indicate the total length of the development path. Next, the number of participants is listed. In our example, we see that in the lower-bound calculation the number of participants is 468, about 75% of the total. In the scenario where high transaction costs were incurred, this drastically decreases to 246, illustrating the impact this can have on the network solution.

The final three indicators present the percentage decrease in total network costs, the total flow in shipments, and the number of sequences in the final network solution. We see that the three types of collaboration influence the network design to a large extent. In this illustrative example the difference between a Type I, II, and III collaboration is the term of the contract related to these types of collaboration, the asset specificity, uncertainty, and additional resources. As the network concept (e.g. a hub-network) is the same in all three scenarios, no additional benefits are introduced when implementing a *Type II*, or *Type III* instead of a *Type I*. In Figure 7-14 the hub-network solution is depicted (δ_{low}) and for all these actors the transaction costs are depicted (see legend). A circle denotes the transaction costs and the additional resistance.

Table 4: Results of the hub network design procedure for 6 test cases

	Collaboration type					
Performance	LB[II]	Type I	Type II	Type III	δ_{high}	δ_{Low}
Total costs	€98,033,760	€101,004,480	€103,480,080	€111,402,000	€115,115,400	€104,717,880
Deviation	1.21	1.31	1.32	1.45	1.21	1.23
CPU(sec)	840	1764	1714	1966	1587	1607
I1-iterations	45.21	54.2	49.2	32.1	15.4	13.4
I2-iterations	21.2	16.4	23.2	19.2	18.3	17.2
Total steps	203	191	195	171	167	198
Participants [I]	468	348	270	252	246	312
%decrease	20.8%	18.4%	16.4%	10.0%	7.0%	15.4%
Total Flow	1,224,600	847,800	706,500	612,300	659,400	832,100
Sequences	18	15	12	8	8	14

[I] the number of participants denotes the number of origin-destinations relations

[II] LB is the lower bound based on the average of 20 runs excluding transaction costs

We assumed that the transaction costs consist of the search costs, bargain, and enforcement costs. We estimated these costs for all actors and assume that they are normally distributed, with an average of €80,000. The results show that most participants, actors that joined the network, have transaction costs below €100,000, but there are participants that joined the hub-network even though transaction costs (>€250,000) are incurred. Although the search, bargaining, and enforcement costs are relatively high the economies of scale achieved when joining the hub-network weigh up against the transaction costs. This example is purely illustrative and the transaction costs crudely estimated, but using the design methodology, we are able to delineate the effects of these costs on the network design and, through scenario-analysis, to evaluate the different development strategies of these types of network.

7.5.2 Evaluation of the network

The next step in our framework, as presented in Chapter 6, consists of the evaluation of the network solution derived from the network design. We use simulation to evaluate the networks, based on detailed order information. We simulated the individual orders, dispatches and shipments and compared the performance of the network (in terms of the integral costs) with the costs derived from the network design phase. We emphasize again that we use simulation to assess the quality of the network solutions derived from the network design procedure. As we do not make an extension on the existing simulation techniques and simulation models we will not go into the evaluation phase in detail. By simulating the network solutions we validated the costs, lead-times, frequencies, etc. derived from the network design, and, in addition, we were able to assess the reliability of the network solution through incorporating the influence of stochastic travel-time, loading times, etc. Table 5 presents a list of several key performance indicators from the design phase that was compared with the performance of the network, derived from the simulation. Basically the key performance indicators listed in Table 5 provide a comparison between, for example, the total network costs derived from the optimization and the total costs derived from the simulation.

Table 5: Evaluation of the network design.

	Network type					
Performance	LB	Simulated LB	δ_{high}	Simulated δ_{high}	δ_{Low}	Simulated δ_{Low}
Fraction of the flow	78.0%	76.3%	42.5%	43.9%	54.3%	54.8%
Total costs	€98,033,000	€100,123,000	€115,115,000	€118,798,000	€104,717,000	€1,057,767,000
Total volume (units)	1,224,600	1,224,600	659,400	680,501	847,800	856,379
Average costs/unit	€16.34	€16.90	€19.21	€20.32	€17.21	€18.20
cycle time (hours)	38.65	36.76	42.1	43.4	39.0	39.4
%decrease total costs	20.8%	20.1%	9.7%	10.0%	15.6%	15.8%
direct shipment costs	78.34	78.46	78.34	78.12	78.34	79.1
handling costs	€9.40	€9.45	€10.97	€11.72	€10.50	€10.60
inventory costs	€2.70	€2.12	€3.37	€3.18	€3.21	€3.24

In Table 5 we compare the LB indicators with the Simulated LB, the δ_{high} performance with the simulated δ_{high} performance, and the δ_{low} performance with the simulated δ_{low}. The network solution derived from the network design phase of our framework were simulated using the RESPONSE™ network design and evaluation suite (Groothedde 2004b) that makes use of Matlab ® version 6.3 and Simulink® 6.2. To be able to simulate the network solutions a lot of effort must be put into the data-collection, implementing the solutions and testing the methodology. Generally the costs derived from the simulation were higher than the costs derived from the network design procedure. The average costs are respectively €16.34/pallet in the LB variant (€16.90/pallet in the simulated LB), €19.21/pallet in the δ_{high} variant (€20.32/pallet in the simulated δ_{high}), and €17.21/pallet in the δ_{low} variant (€18.20/pallet in the simulated δ_{low}). This is primarily caused by the unreliability in shipment times and missed delivery time windows introducing additional costs not taken into account during the design phase.

8 Case study: a collaborative intermodal hub network

Collaborative hub networks can provide an answer to the need to decrease logistics costs and maintain logistics service levels by shifting consolidated flows to modes that are better suited for handling large volumes so that economies of scale can be obtained. Especially in the retail sector this necessity has been increased by the tendency towards smaller shipments sizes, higher frequencies, and the overall fragmentation of flows. There have been several initiatives, in which firms either vertically or horizontally collaborate. It is, however, still very difficult to predict whether or not an initiative is feasible.

Distrivaart is such an initiative in the design and implementation of a collaborative network in which delivery frequency and shipment reliability meet the requirements set by the participants. In order to comply with these service requirements and achieve economies of scale the combination of flows of the different manufacturers and retailers is sought. This specific concept, first proposed by Vermunt (1999), won the *European Intermodal Award* of the European Intermodal Association in 2003 and is still a concept that receives ample attention in the media. In *Distrivaart* a distinction was made between the various stages of development in the project: first of all, there is the *Transport Network* with the emphasis on how transport services are rendered, given the shippers' demands. This is all about the best possible use of modes of transport, without involving a type of vertical chain management, and scant information exchange, classified as a $\bullet/\bullet/Sc/R/\sum_{\text{costs}}, I$ problem. Secondly, there is the *Distribution Network*, in which there is greater emphasis on the coordination between various participants in the chain and where some form of chain management is desired, ($\bullet/A/Sc/\bullet/\sum_{\text{costs}}, II$). Finally, a third stage is distinguished: the *Collaborative Network*, which entails an intensive form of chain integration that requires that manufacturers, retailers and service providers allocate orders and products to the different buyers based on a continuous exchange of information regarding current patterns of demand ($S/A/\bullet/\bullet/\sum_{\text{costs;service}}, III$).

In Chapter 6 the framework for the design of collaborative networks was presented followed by the mathematical description of this framework translated into the network design algorithms in Chapter 7. In this chapter the methodology developed during the *Distrivaart* project will be demonstrated and evaluated using a case study. We focus on the network design aspect of the project *Distrivaart*, performed by the author. For additional information concerning the overall project we refer to NDL *et al.* (2003), Groothedde, *et al.* (2001;2002), Groothedde and Rustenburg (2003), Groothedde *et al.* (2005) and Appendix F:The Distrivaart project, in which a brief overview of this project is presented. The case study is based on the information and insights from the Distrivaart project that started in 1999 and ended in 2003. During this project a hub network concept was developed and evaluated during a pilot. In this network concept a dedicated pallet barge is used for the inter-hub transfer of pallets. During the project the network solutions, derived from the network design methodology, were all extensively evaluated using simulations. However, we will only briefly discuss these results as the focus of this dissertation is on the design of collaborative networks. The network design of the hub network was based on a data set that comprised of more than 250 retail warehouses and approximately 200 production locations. The flows between these locations, currently all shipped using road transportation, were categorized in 26 product categories.

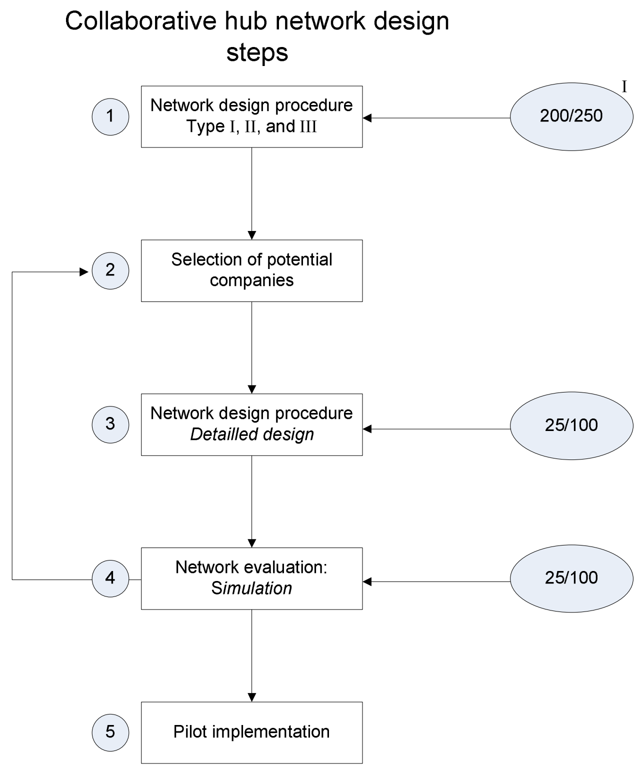

Figure 8-1: Overview of the network design approach in the *Distrivaart* project

I) The first number indicates the number of origins, in this case the production locations or warehouses. The second number indicates the number of destinations; the retail warehouse, wholesalers or other stock points.

An in-depth analysis of the network solution was carried out using detailed information provided by several key manufacturers of *Fast Moving Consumer Goods* (FMCG). In the remainder of this chapter we will refer to this group as the *focus-group*. This group of potential participants consisted of: Heineken, Bavaria, Grolsch, Coca Cola, Interbrew, Kimberly-Clark, Douwe Egberts, Unilever Bestfoods, Lever-Fabergé, Vos Logistics, Van Heezik, and Riverhopper. This detailed information (up to individual order-lines) was used to construct the necessary data set for an additional design cycle and the evaluation of the network solutions using simulation.

This additional design cycle was undertaken to design a feasible and acceptable starting network for the pilot implementation and convince the members of the focus group that the hub network concept was feasible and implementable. In Figure 8-1 the different steps are depicted. In this figure the first design cycle was based on approximately 200 production locations and 250 retail warehouse and wholesalers, making up the origins and destinations. The in-depth analysis was based on the information provided by the focus group that comprised 25 origins and approximately 100 destinations. This same data set was used for the simulation of the networks. Then finally, outside the scope of this research, the implementation of the network (in the form of a pilot) was carried out. The results and insights of the pilot will be discussed in section 8.5. Firstly, in the following section the concept of a collaborative network is described and as this concept makes use of two modes of transport, both will be discussed in detail. In addition, a detailed description of the data set used to design the networks and of the focus group participants will be presented. In 8.1.2 the three different types of collaboration are discussed, listing the characteristics for the three different types of collaboration and the possible impact this can have on the network solutions.

8.1 The concept of a collaborative hub network

The hub network concept is referred to as a dedicated pallet barge network in which specially equipped barges are deployed on the inter-hub connections. The collection and distribution is carried out by road transportation. In addition to shipment using these barges, direct road transportation is still used. This idea of transporting pallets using inland shipping is not new and has been explored in many recent initiatives.[27]

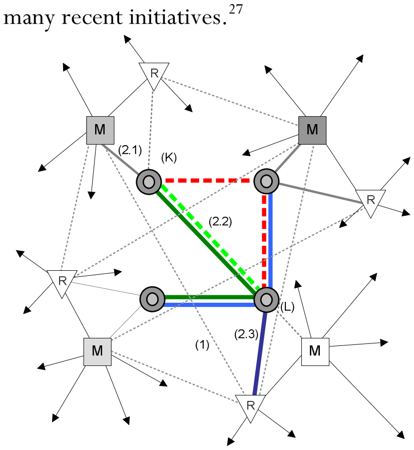

Figure 8-2: Schematic overview of the hub network.

However, the concept in this specific configuration, first proposed by Vermunt (1999), explicitly explores the possibility of collaboration and the accompanying economies of scale and scope made possible by joining forces. The problem with a network that deals with loads

[27] In 1993, for example, the question of whether Unilever's dairy products could be transported by water was examined (Schuttevaer, 1999). In 1995, there was an initiative in Germany, in which KWS Systems played an important role and Coca-Cola was named as a potential client for waterway transport using pallets. (Schuttevaer, 1998).

that are quite small by traditional standards of inland shipping is that the utilization is too low to be competitive, leading to costs higher than the alternative modes. However, by combining the flows of different shippers, both the utilization and the delivery frequency can be kept high. This is especially so in the segment of FMCG, in which the shipment sizes are relatively small and frequencies high. In Figure 8-2 the concept is illustrated in more detail; two alternatives are illustrated. The first is direct transportation from manufacturer to the retail warehouse (denoted (1) in Figure 8-2). The second alternative consists of shipment through the hub network. When making use of the hub network the products are shipped from the manufacturer to the nearest hub (k) by truck (2.1); the pallets are then transshipped from the truck onto a dedicated pallet barge and then transferred from the hub near the origin (k) to the hub near the destination (l) via segment (2.2). Then the pallets are unloaded from the barge onto a truck and finally shipped to the retailer; the final destination (2.3). In addition, different inter-hub services are depicted in Figure 8-2. As these barges have a considerable capacity economies of scale can be achieved on this segment of the intermodal route.

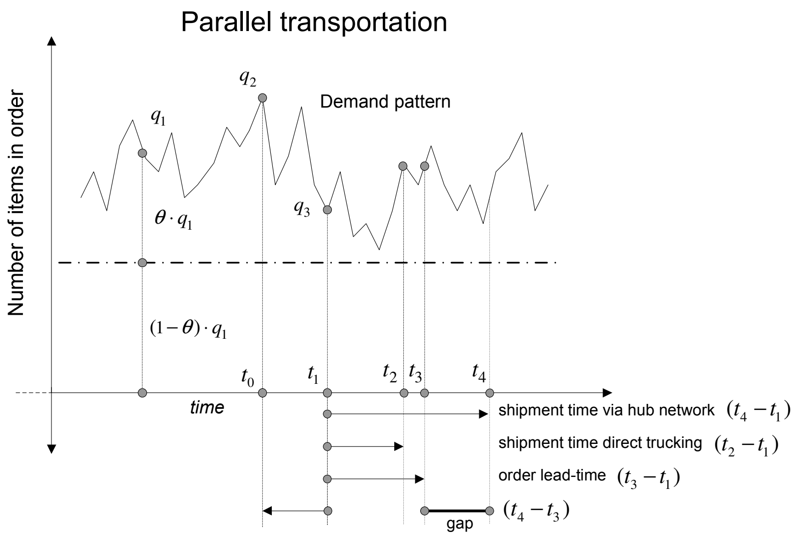

Figure 8-3: The concept of parallel transport between origin and destination to deal with demand peaks.

It is however essential to combine this inter-modal route with direct trucking that provides logistic services for short distances and excess demand that cannot be accommodated through the hub network (denoted 1 Figure 8-2). In other words: in this concept the combination is made between the capacity of inland barges and the responsiveness and flexibility of road transport; economies of scale and scope can thus be guaranteed. In this example the barge continues its journey from k_1 to k_2 and finally reappears at hub k_3 . In this concept the barge must return to its starting hub due to the fact that in this segment of FMCG a substantial fraction of the flows has packing that needs to be returned to the origin, so $s = \langle k_0, k_1, ..., k_n, k_0 \rangle$. Using inland shipping means that the shipment time will increase considerably compared to road transportation. For example, on average it takes 10-15 hours to cover 150 kilometers using an inland barge. To cover the same distance by truck would take approximately 2 hours. This would not really be a problem if the value density is low and demand can be accurately predicted making it possible to send the products in advance, before the order is placed. But in practice this is usually not the case.[28] In Figure 8-3 this is illustrated using a simple example In this figure the erratic order pattern of a single customer is depicted. The order lead-time in this example is set to ($t_3 - t_1$). The shipment time using direct trucking, including order entry, picking and loading, is ($t_2 - t_1$). This means that it is possible to accommodate demand well within the customer lead-time (with some margin). If the same shipment was sent using the hub network the shipment time would be ($t_4 - t_1$). There is a lead-time gap between customer lead-time and hub shipment lead-time of $(t_4 - t_3)$. In this example this would mean that to accommodate demand within the customer lead-time at t_3 (placed at t_1), the shipment via the hub network needs to be shipped at t_0. However, at t_0 the order is not yet placed so it had to be sent in advance, based on a predicted order volume. The problem is, however, that demand on t_0, (denoted q_2) exceeds demand q_3 at t_1 considerable. If not accurately forecasted this probably would result in sending too much in advance.

Designing the hub network on these peaks in demand would mean a considerable access capacity most of the time, yielding a low utilization. These issues can be addressed by using both alternatives, road transportation and the hub network in parallel. For example, shipment via the hub network for the part of demand $(1-\theta)\cdot q_1$ that is stable in nature and can be well predicted. In addition direct road transportation is used to accommodate the peaks in demand $(\theta)\cdot q_1$. The height of $(1-\theta)\cdot q_1$ is to be determined for every origin and destination (customer relation) and is typically a question that can be answered using simulation where the fraction θ can be tested and fine-tuned based on different order patterns.

8.1.1 The potential participants of the collaborative network

Retailers in the Netherlands are being faced with many significant changes today; increased competition is creating pressure on retailers to simultaneously control costs and improve customer service. The market for this segment of products, dominated by a relatively small number of retailers in the Netherlands, has great potential for the start of a collaborative hub network. In the *Distrivaart* project the aim was to develop an intermodal hub network with relatively small barges, capable of handling pallets, the loading unit most frequently used in the distribution of products in the FMCG sector. At 293 million pallets per year, the Dutch market for pallet transportation is considerable and dominated by FMCG, semi-finished goods, and building materials (Groothedde *et al.* 2001). Of the approximately 80 million pallets per year of consumer goods, 43 million are non-perishable/ambient fast-moving consumer goods (beer, soft drinks, sanitary paper, pet food, etc.). In Figure 8-4 an overview of the different product segments is depicted with the pallets per year shipped and the fraction of the flow that is shipped using the pallet as a loading unit. A second reason why the FMCG focused on in the *Distrivaart* project, was the concentration of production in this segment. For example, beer (Bavaria, Grolsch, Heineken and Interbrew together supply 97% of the domestic market), coffee (Douwe Egberts), sugar (CSM, Suikerunie), soft drinks (Vrumona,

[28] In the fourteenth UPS Business Monitor accurately forecasting demand was thought to be biggest challenge by the approximately 1500 European managers in 2004 (UPS, 2005).

Coca-Cola) and crisps (Smiths) and the comparable concentration and scale of operation of the customers of these producers (Albert Heijn, Schuitema, Laurus en Aldi). In addition, the characteristics of the goods and shipments play a large role, as this market segment involves predominantly bulky goods that need to be transported at high frequency and in large shipments. And finally, the problems in today's road transportation concerning reliability and costs are becoming ever more prominent, making the chances of an alternative mode of transport more favorable. In this segment the pallet is the common loading unit between the production location and the retail warehouses, mostly shipping goods on industrial pallets, although various studies have revealed a slow but steady shift towards the use of Euro pallets. While the industrial pallet remains the favorite for domestic shipping, the Euro pallet is increasingly being used for export. *Euro* pallets and *Pool* pallets (pallets rented from a third-party operator) are by far the most important types. There have, however, been developments that may have a great influence on the *Distrivaart* concept, such as the use of roll containers, which do not need to be re-packed in the distribution center before they are sent to the shop.

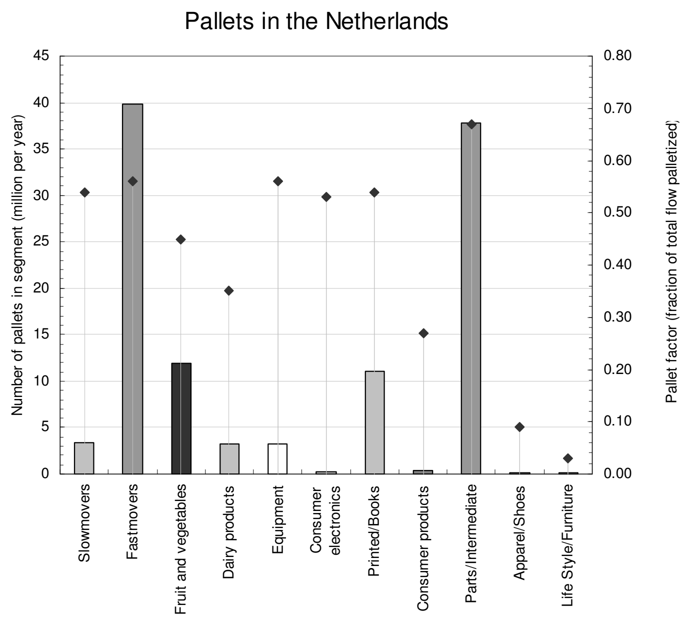

Figure 8-4: Overview of the pallets per year shipped in the Netherlands (Consumer products). Source: Groothedde *et al.* (2001).

This could lead to a reduction in the use of pallets for the trip from producer to buyer. At present, the distribution of pallet formats in the Netherlands is as follows: 39.7% industrial pallets (1.0x1.2), 58.1% Euro pallets (0.8x1.2) and 2.2% other sizes (Rijnconsult 1998; Thijs *et al*. 2001).

In order to comprehend the possibilities of a collaborative hub network an extensive market analysis was first performed. This analysis, which examined Dutch retailers and manufacturers in the fast-moving consumer goods market, resulted in an estimate of the potential market, mapping the production and incoming product flows of the warehouses (inbound), broken down into 28 product categories. Together, these manufacturers and retailers transport a volume of 26.3 million pallets annually between the mentioned 250 production locations and 200 distribution centers (Groothedde and Rustenburg 2003). In total 275 companies were closely involved in the project and the information provided by the manufacturers and retailers made it possible to make a relatively accurate estimate of the pallet flows between the manufacturing location and the retail distribution centers.

In Table 6 an overview of the in total 275 companies and organizations involved are listed. The largest group was formed by the manufacturers (food and non-food), indicating that the initiative for this concept clearly lies with this group. During the project in total 60 interviews were conducted, with again a focus on the manufacturers (the shippers). To make it possible to accurately estimate the current pallet flows between the production locations and the retail warehouses, used in the network design methodology, detailed information of 51 companies was used, manufacturers, retailers, carriers and service providers. If no data was available an estimate of the flows between the origin and destination was generated.[29]

Table 6: Overview of the involved companies and organizations in the *Distrivaart* project

	Companies and organizations				
Type of participant	Total[I)]	Interviews[II)]	Workshop participant	Provided detailled information	Pilot participants
Manufacturer Food	34	19	25	23	5
Manufacturer Non-Food	27	10	5	4	1
Retailer Food	19	5	9	4	3
Retailer Non-Food	7	2	0	7	0
Logistics Service provider	23	9	33	8	1
Carrier	12	2	2	0	0
Carrier (Inland Shipping)	9	5	9	4	1
Terminal Operator	5	0	2	0	2
Financial Organization	11	1	9	1	0
Trade Organization	14	3	6	-	-
Ministry	9	1	0	-	-
Consultant	42	0	9	-	-
University	12	3	0	-	-
Information technology	51	0	0	-	-
Total	275	60	109	51	17

[I)] The total companies and organizations during the 4 year period of the project was well over 300 but here only those companies, organizations and stakeholders are listed, that either participated in the workshops, provided information, or attended the project meetings.

[II)] During the project interviews were conducted to inform potential participants and gather detailed information.

Appendix E: Dataset characteristics gives an overview of the characteristics of the dataset based on the information provided by the companies listed in Table 6. This data set contains in total 26,321,000 million pallets distributed over 26 categories and next to the annual pallets flows, the number of production locations, the average shipment size, and the average delivery frequency in shipments per week to the customers (between the production location and the retail warehouse). The average delivery frequency in this data set is 5.4 shipments per week. Finally, based on the provided order information the percentage of the shipments between the manufacturer and the retailer that is sent in Full-Truck-Load (FTL), or Less-then-Truck-Load (LTL) was calculated. In the total dataset 62% of all shipments are sent in FTL's, 38% in LTL's.

[29] Based on market share, footprints, workforce, annual turnover, etc. and the data received from similar manufacturers, retailers and wholesalers the pallet flows were estimated (Groothedde *et al*. 2003)

The sales per week in pallets were on average 512,000 pallets/week over all 26 product categories, with a peak of +16.8% above average in week 31, and a minimum of -18% below average in week 8. This indicates that when designing a hub network that needs to yield a high utilization of the assets these sales patterns are extremely important and have to be taken into account, as indicated in the previous section.

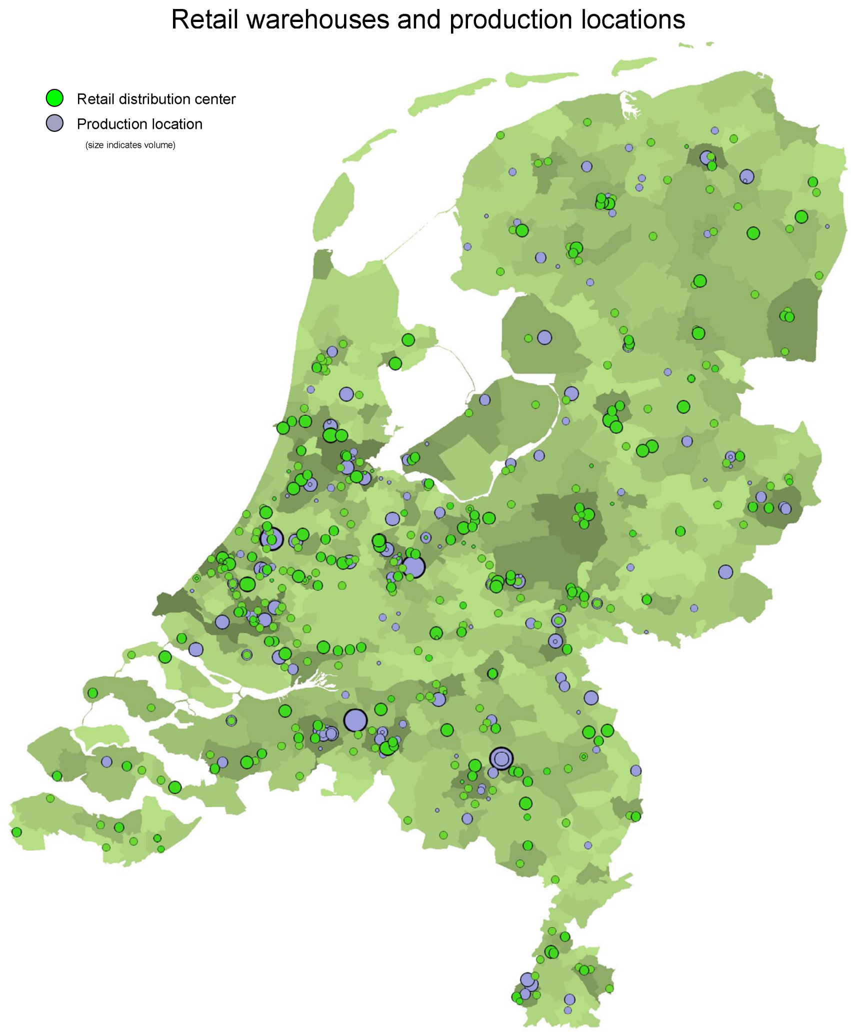

Figure 8-5: Overview of the locations of the retail distribution centers and production locations. Source: Groothedde *et al.* (2003).

In Figure 8-5 an overview of the retail distribution centers and production locations (manufacturing or warehouse) is presented. The size of the circles indicates the outbound (production locations) or the inbound pallet flows (retail distribution centers), based on publicly available data. The focus group which provided the information that was used to conduct a detailed analysis of the network design methodology consisted of nine key manufacturers in the Netherlands, two logistics service providers and the inland shipping carrier. In Figure 8-6 the locations of the manufacturing sites, production warehouses, retailers and additional customers are depicted. They provided detailed information on the orders and product flows between the manufacturing locations (20) and retail warehouses of four of the largest retailers in the food.

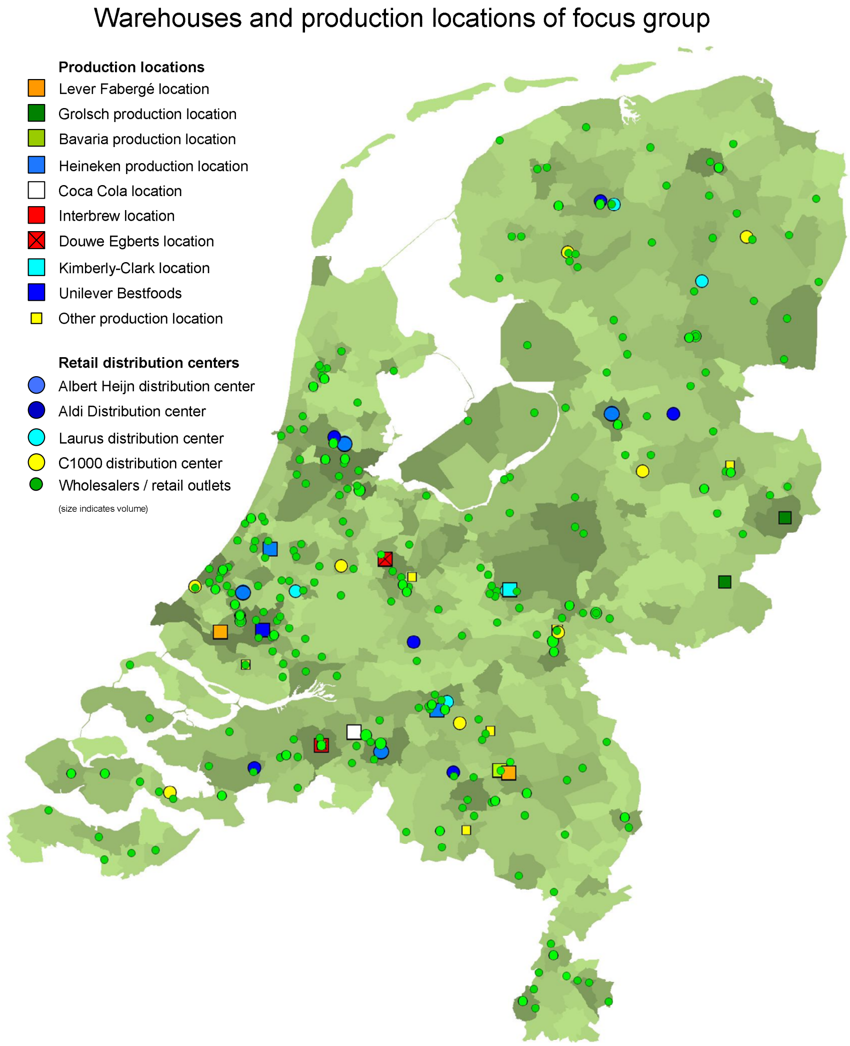

Figure 8-6: The retail distribution centers and production locations of the focus group. Source: Groothedde *et al.* (2003).

Albert Heijn, Schuitema, Aldi, and Laurus, wholesalers, and additional customers, add up to in total 100 customer locations. In total this detailed data set included 6,310,000 million pallets per year. The average sales (in pallets per week) of the focus group is on average 119,000, with a peak in week 32 of 25% above average and -25% below average in week 8.

8.1.2 The different types of collaboration

To provide a guideline for the development of the hub network a number of scenarios were constructed during the *Distrivaart* project, in which different collaboration types were distinguished. By using contrasting scenarios and collaboration types the variation in development, feasibility and the choice behavior of the participants can be explored.

The three types of collaboration that were distinguished are: (1) the *Transportation Network* , a type I operational collaboration ($\bullet/\bullet/Sc/R/\sum_{\text{costs}}, I$) , (2) the *Distribution Network*, a type II coordination collaboration ($\bullet/A/Sc/\bullet/\sum_{\text{costs}}, II$), and (3) the *Collaboration Network*, which is an example of a type III network collaboration ($S/A/\bullet/\bullet/\sum_{\text{service}}, III$). The first variant is the network with an emphasis on how transportation is rendered and equipment is deployed. The focus is on the scheduling and resource planning which is all about the best possible use of the equipment and labor without involving vertical or horizontal logistics management. The second network, the *Distribution Network,* in which there is greater emphasis on coordination between the various participants in the network, entails a new governance structure facilitates the participants to exchange information and manage the orders, products and information flows. A crucial difference is that during the inter-hub transfer the products can be re-assigned to other customers, something not foreseen in the *Transport Network.* Finally, the *Collaborative Network*, which entails an intensive form of network integration that requires that manufacturers, retailers, and service providers to allocate orders to the different customers based on continuous and transparent information exchange. The inland barge and hubs would function as pipeline inventory that can be allocated and re-allocated based on the order-patterns.

The first stage is a collaboration type that is straightforward with an emphasis on the utilization of the resources and is classified as a type I operational collaboration. This type of network consists of a horizontal collaboration between manufacturers and focuses solely on the transportation of pallets between the manufacturer and the retail warehouse. In Figure 8-7 a schematic representation is given. In this figure the manufacturers (denoted M) are within the circle indicating the collaboration. The retailers, denoted R are not part of the collaboration, neither are the carriers (C), terminal operators (T), or the inland shipping carriers (I). Suppliers (S) and raw material suppliers (R) are not a part of the consortium.[30] The order decoupling point is located at the manufacturer's warehouse so that no un-allocated products are present on the inland shipping barge.

The consortium of manufacturers signs a contract with the carrier, terminal operator and the inland shipping carrier for a 1-year minimum for a fixed or minimum volume that is sent via the hub-network. In the fast moving consumer goods sector the dominant party is clearly the retailer so there is downstream dominance present in the network.[31]

[30] Although there were some initiatives to include the flows of some suppliers that could be combined, for example the flows of packing materials like glass, bottles and intermediate products.

[31] During the project and in the interviews the fact that the retailers were not a part of the collaboration was certainly an important issue. If they were not included no changes or flexibility implementing a concept like this was to be expected. Including them in the collaboration was seen however, as a risk due to the dominance they have in the logistics network and as a result are very dominant in the value appropriation.

The consortium members sign an agreement on the volumes and gain sharing issues that occur. The asset specificity consists of the dedicated inland shipping barge, the manpower needed to govern the network. The transaction costs are considerable due to the fact that four contracts need to be drawn, negotiated and controlled. The manufacturers are responsible for the collection and distribution (by truck). As the retailer is not a part of the collaboration, no changes in the time windows and service levels are to be expected due to the *Transport Network*.

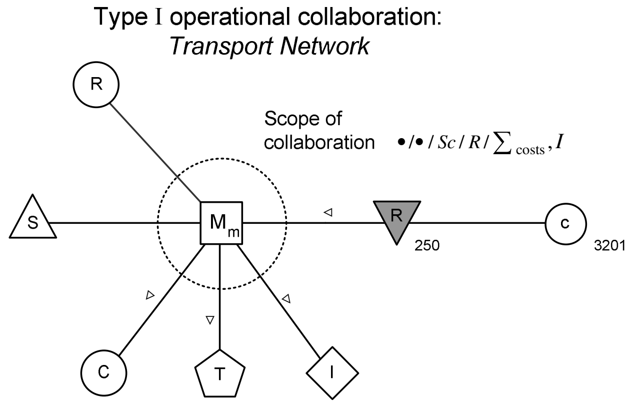

Figure 8-7: Schematic representation of the *Transport Network* stage.

In the second stage, the *Distribution Network,* the collaboration not only consists of the manufactures (M) but also one or more logistics service providers are a part of the collaboration (L). Figure 8-8 is a schematic representation of this type II collaboration. The aim of this collaboration is to coordinate activities required to supply the retailers and achieving economies of scale by combining the flows and in addition increase the level of service if possible. In this case the decoupling point is located at the manufacturer's location or on board of the inland barge. The manufacturer sends a fixed quantity of product via the hub network and, during the transfer, the customer allocation takes place. The logistics service provider takes care of the collection and distribution, using either carriers already contracted by the logistics service provider or local carriers that are contracted to carry out the collection and distribution. The manufacturers *outsource* their entire volume to the logistics service provider. In Figure 8-8 two carriers are depicted (C1 and C2). C2 is added in this figure because it is likely that the service provider already is tied to several carriers (in-house or outsourced). The contracts with the carrier for the collection, distribution and the direct transport are taken care of by the logistics service provider. In addition the service provider contracts the terminal operators and the inland shipping carriers. The terminal operator is responsible for the transshipment of the pallets at the hub and the temporal storage of the pallets if necessary. This temporal storage can be necessary to comply with the service level agreements with the retailer, who are still no part of the collaboration. The consortium covers the risk, asset specificity and transaction costs (e.g. pallet handling system, handling equipment at the hub, and the information system). The third stage is referred to as the *Collaborative Network* which is a Type III collaboration. In this network the emphasis is on collaboration between the manufacturers (M), logistics service provider (L), and the retailer

(R). In this initiative the information of the production, sales and pipeline inventory is shared and the service provider, responsible for the logistics management, tries to optimize the product availability of the network minimizing the logistics costs. Information exchange is executed using *CPFR* techniques.

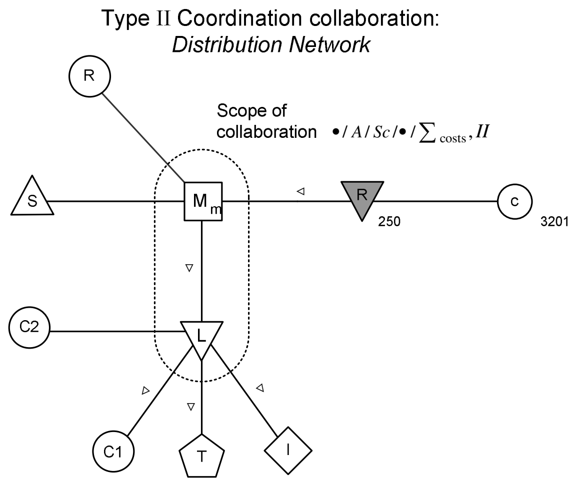

Figure 8-8: Schematic representation of the *Distribution Network* stage.

The service provider tries to accommodate the customer demand, based on daily demand, production planning, and the available pipeline inventory, maximizing the use of the hub network, complying with the service level agreements with both the manufacturer and the retailer.

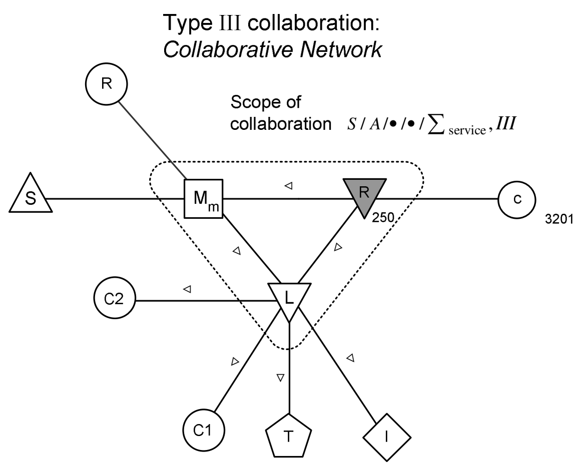

Figure 8-9: Schematic representation of the *Collaborative Network* stage.

The service provider contracts the carriers, inland shipping carrier and the terminal operators and governs the available capacity in both the hub network and the direct road transportation. Out-of-Stock and the inventory levels are the most important internal performance indicators.

The specific assets are the equipment and facilities needed at the hub, the pallet-handling equipment needed at the inland barges, the information systems required and the workforce needed to govern the collaboration. The consortium shares the risk and the asset specificity equally and the term of this type of collaboration is a minimum of 3 years. This kind of collaboration demands a lot of changes throughout the logistics network and it is very difficult to predict the benefits upfront, and the uncertainty in the height and type of benefits is relatively high. A final complicating factor is the dominance of the retailer, part of the consortium, probably resulting in the manufacturer (M) and the service provider (L) demanding additional safeguards.

8.2 Cost calculation

In the previous section we discussed the characteristics of the hub network and the three different types of collaboration that were foreseen in the *Distrivaart* project. Using the Activity Costing Methodology discussed earlier in 5.1.3. Before we present the results of the three types of collaboration, an example of such a cost calculation is presented. Based on a specific origin destination relation, the shipment costs of sending an order through the hub-network and sending this same order using direct truck transportation are compared. In order to illustrate both these alternatives it is necessary to make some assumptions on the utilization of the equipment, the capacity deployed and the cycle times. Firstly we provide a detailed overview of the two alternatives, illustrating the different activities, objects, actors and information flows. These different activities include motion, handling, waiting, and administration. In addition, an overview is provided of the key input parameters and attributes.

In Figure 8-10 the structure of the hub-network alternative is presented; the top-half of this figure illustrates the information and order-flows between the different actors, active in this alternative. The bottom-half of this figure illustrates the physical chain, with the manufacturing sites, hubs, and retailers. For these locations and objects in the chain different key parameters are included. The hub-network alternative includes at least 6 different actors: manufacturer (M), logistics service provider (L), retailer (R), terminal operator (T), inland shipping carrier (I), and carrier (C), and 7, 8 or 9, if the collection, distribution and direct transfer truck carrier are not the same and there are separate terminal operators.

Retailer (R) sends its orders to manufacturer (M) who in turn sends the order to the service provider (L). The service provider has a central pivotal position in this alternative and governs the hub-network. The service provider sends a transport order to the collection carrier (privately owned or third-party) for the collection of the products. Then, depending on the type of network and the itinerary regime, the service provider sends an order to the inland shipping carrier (I). The terminal operator (T1) is then responsible for the transshipment of the loading units at the hub and transships the pallets onto the pallet barge, either directly from the truck onto the barge or, if intermediate storage is used, the pallets are first temporarily stored, introducing additional handling. When the shipment arrives at the destination hub, the service provider sends a transport order to the distribution carrier, before the shipment is finally delivered to the retailer.

There are some key assumptions that have to be made before the costs of the alternative can be derived and the network can be optimized. The level of these parameters is part of the scenario definition. For example, during the project several transshipment techniques were tested (forklifts, fully automated systems, cranes, conveyors, etc.).

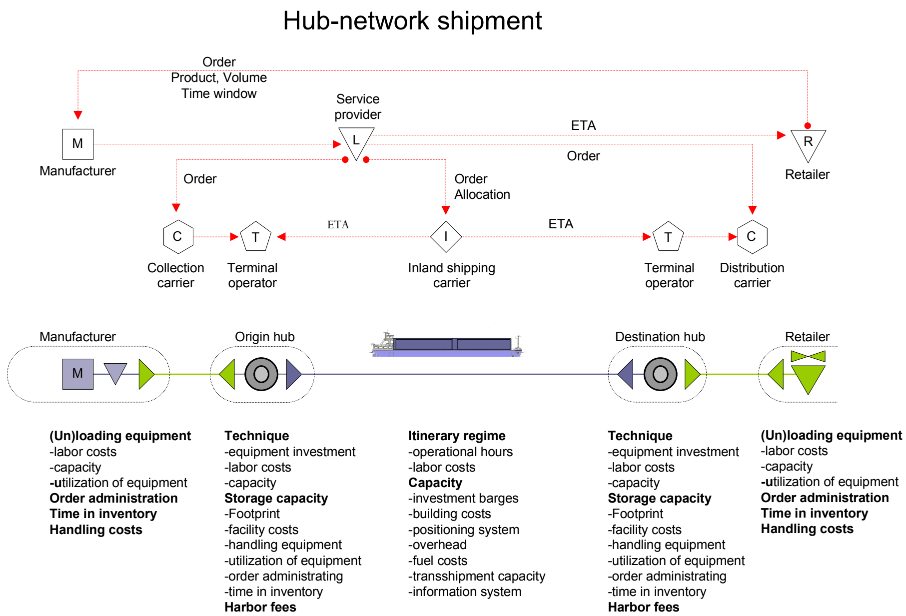

Figure 8-10: Schematic overview of the hub-network alternative with actors, information and order flow, and the physical structure of the chain.

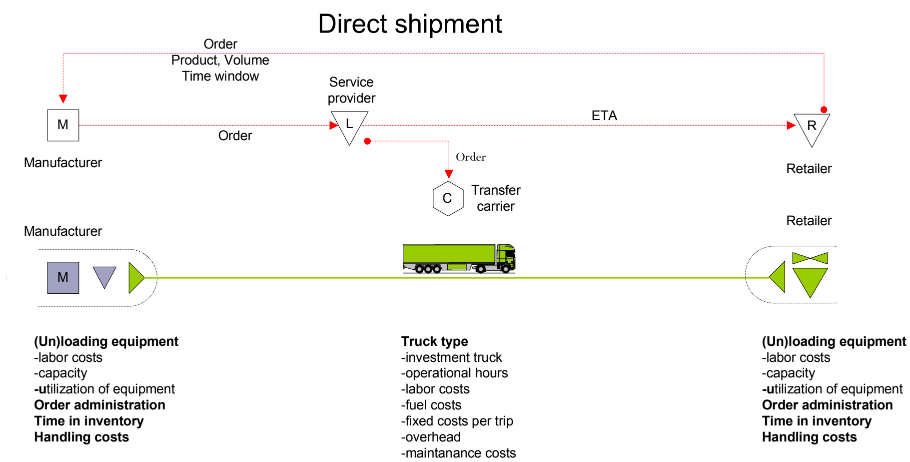

Figure 8-11: Schematic overview of the direct shipment alternative with actors, information and order flow, and the physical structure of the chain.

The capacity of these systems in pallets/hour, as it turned out, is a key aspect of the concept. Another predominant characteristic of the concept is the itinerary regime that is implemented. Finally, the type of barge that is deployed is, of course, a vital element in the concept. The capacity of the dedicated pallet barges is a very important characteristic of the network. In Figure 8-10 these key characteristics are listed, and need to be determined, before the network optimization and incorporated cost calculation can be started.

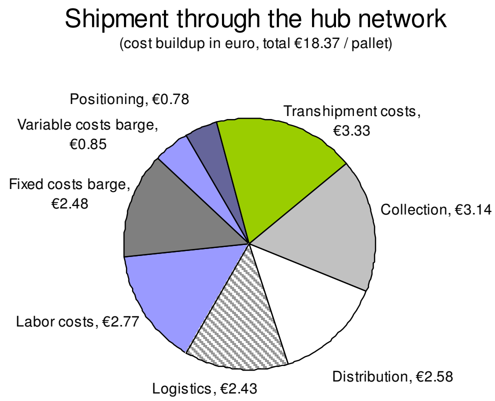

Figure 8-12: Cost breakdown of the-hub network alternative excluding the transaction costs and additional resistance.

The example presented in this section is the cost breakdown of a typical origin-destination relation on which 40,000 pallets are shipped annually (in Full-Truck-Loads). The value of the pallets is €1,450,- and the interest rate is 5.6%. For this example the utilization of the assets (barges, handling equipment, storage, etc.) is assumed to be 92%. The itinerary regime in this example is semi-continuous, which means that the barges are operational 18 hours per day.

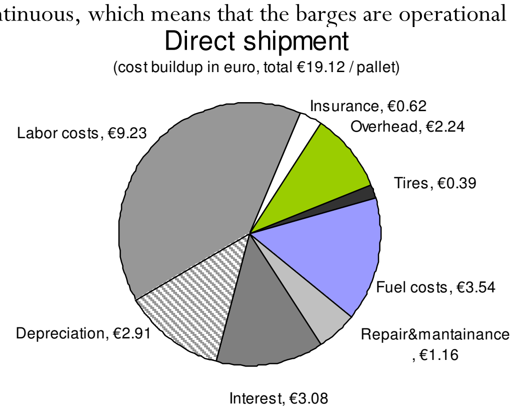

Figure 8-13: Cost breakdown of the direct road transport alternative excluding the transaction costs and additional resistance.

The capacity of the barges is 560 pallets and the transshipment capacity on both hubs is assumed to be 220 pallets/hour. In our example the costs of the hub-network alternative are €18.37/pallet; the costs of the direct shipment alternative €19.12/pallet (distance is 231 kilometer). Of course no conclusion can be drawn from this, but we present both cost breakdowns to illustrate the completely different buildup of the costs. For shipment through the hub-network the fixed costs (including labor) only make up for about 25%. However, the transshipment costs at the hub and the collection, and distribution cost transportation (shipping the pallets to and from the hub by truck transportation, depicted (2.1) and (2.3) in Figure 8-2), dominate the costs with 49% of the costs per pallet. If the storage costs at the hub are added, this adds up to 69%. In other words: 69% of the costs of the hub-network alternative are consumed by collection, distribution transport and the activities at the hub. This illustrates the necessity of cost-efficient and fast transshipment at the hub and minimization of the distance between the origin and destination and the hub.[32] For the direct shipment alternative using trucking, the annual fixed costs and the labor costs are the dominant components.

8.3 The influence of the type of collaboration

The three different types of collaboration were presented in sub-section 8.1.2 and the different characteristics were discussed. In the following sub-sections we will present the results of the network design calculations and discuss the different derived network solutions. Before we present the results, in terms of integral network costs, transaction costs, network configuration and the development paths for different transaction costs scenario's we first present the different parameter-settings for these three scenarios, representing the three *Distrivaart* collaboration types: *Transportation Network*, *Distribution Network*, and the *Collaboration Network.* Table 8 presents the different parameters used for the network optimization. The *Transport Network* focuses on FTL's, as it is basically a simple transportation network. If FTL-shipments are selected from the dataset (see Appendix E: Dataset characteristics) 14,320,000 pallets are included in this network design. We argue that because the retailer is not participating in this collaboration, the service levels do not change and therefore it can be assumed that there are no changes in shipment size. The average shipment size in this scenario is 26 pallets. In the *Distribution Network*, this drops to 14.4 pallets and in the collaboration network to 9.8 pallets. Another key characteristic is the average value of the pallets: €1600/pallet in the *Transport Network*, increasing to €3200/pallet in the *Collaboration Network.* In the *Transport Network* and *Distribution Network* the itinerary regime of the inland barges is semi-continuous, meaning that the barges are operational 18 hours per day. In the Collaboration Network the itinerary regime is set to 24 hours, 7 days a week. The investment in the barges is the same in all three scenarios, however, the pallet-handling equipment, not incorporated in the *Transport Network*, is more sophisticated in the *Collaboration Network.* As illustrated by the cost breakdown illustrated in Figure 8-12, the capacity of this equipment is essential. An important difference between the three networks is the information system that needs to be implemented to be able to accommodate the order and information flows between the actors in the network. In the *Collaborative Network* a sophisticated information and planning system is required.[33] If we look at the different types of collaboration we can observe

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[32] See Appendix G: Overview of the cost components for a complete list of all parameters and constants, that were filled in to calculate the costs of these two examples. The investments and details on the dedicated pallet barge were provided by Riverhopper B.V, the cost information on the direct shipment alternative was derived from the interviews and information provided by the carriers and LSP's involved in the project.

[33] See for more information on the information system and different solution that were developed during the Distrivaart project MP-Objects, (2002).

that the complexity increases (information, orders, governance, etc.); the investments in equipment and information systems increase; the potential volume in pallets increases; the shipment sizes decreases; and the contract term increases. Due to these increased investments, the information system requirements, and complex governance structure, the asset specificity and transaction costs increase. However, the average logistics costs per pallet for direct shipment also increase from the *Transport Network* to the *Collaborative Network.*

Table 7: Overview of the scenario specific parameters.

		Scenario description		
Variable	Units	Transport network	Distribution Network	Collaborative Network
Total pallet flows	pallets/year	14,320,000	26,310,000	26,310,000
Average SKU/order	SKU/order	2.90	9.40	16.20
Average Shipment size	pallets	26.00	14.40	9.80
Percentage FTL	-	0.82	0.67	0.53
Average leadtime	hour	19.4	22.6	34.3
Time in inventory	hour	-	12.6	6.4
Value/pallet	€/pallet	1,600.00	2,300.00	4,200.00
Regime	-	Semi-continuous	Semi-continuous	Continuous
Operational hours	hours/year	1,632	1,760	2,240
Investment barge	€	1,123,000	1,123,000	1,123,000
Investment Equipment	€	120,000	310,000	310,000
Investment Positioning	€	0	500,000	500,000
Building costs ship	€	65,000	75,000	85,000
Overhead	€/year	35,000	65,000	65,000
Information System	€	30,000	120,000	320,000
Capacity barge	pallets	560	560	560
Transshipment capacity	pallets/hour	120	220	220
Fuel costs barge	€/hour	15.00	16.00	16.00
Maintenance costs	€/hour	3.00	4.00	4.00
Harbour fees	€/year	15,000	20,000	20,000
Type of collaboration	-	I	II	III
Contract term	year	1.00	2.00	3.00
Order allocation	-	fixed	dynamic	real-time

In the next three sub-sections we will present the results of the network design of the three types of collaboration. We present the lower-bound (LB) variant, in which no transaction costs and additional resources are included, the variant with high transaction costs (δ^{tc}_{high}), and a variant with low transaction costs (δ^{tc}_{low}). We present the total network costs, the total cost reduction and additional performance indicators of the network solution. In addition, we delineate the network development and the network configuration.

8.3.1 The Transport Network, *Operational collaboration*

The first stage is the *Transportation Network*, a *Type I* collaboration focused on the transfer of FTL's. In total 14,320,000 pallets annually are being transported in the starting situation, all by truck, with an average cost/pallet of €11.32. The total network costs before the optimization are €176,818,000. Then using the network design methodology the lower-bound solution is derived (LB), with no transaction costs and additional resistance incurred. Table 8 presents the overall results of the network optimization of the scenario. The results of the lower-bound variant are presented in the column LB-network.

The total network costs are € 162,367,000, a reduction of €14,451,000 (-8.9%). In total 7 sequences are included in this network solution, connecting 10 different hubs. In Figure 8-14 these 7 sequences are depicted. The number of barges deployed (with a capacity of 560 pallets) on these sequences is 38. The average costs per pallet for shipping a pallet through the hub-network is €12.45. The volume accommodated by the hub-network is in total 2,470,000 pallets, 17.25% of the total annual volume. The network is comprised of 10 hubs, with two central hubs; Schiedam and Drachten. Each sequence includes 4 or 5 hubs and on average 7 barges are deployed per sequence. The cycle times in the final network solution varies from 6 hours (time between two consecutive barges) to 12 hours.

Table 8: Results of the hub network design procedure: Transport Network

	Results of optimization		
Variable	LB-network	High Transaction costs	Low Transaction costs
Network Structure			
%total flow through hub	17.25%	9.65%	13.35%
Total volume	2,470,000	1,382,000	1,912,000
Number of participants	79	45	62
Number of sequences	7	4	5
Capacity deployed	38	20	25
Performance			
Total network costs	€162,367,000	€170,435,500	€168,427,600
Total Transaction costs	€0	€2,434,500	€1,692,600
Total cost reduction	€14,451,000	€6,382,500	€8,390,400
Average costs /pallet	€12.45	€16.08	€13.98
Average transaction costs	€0	€54,100	€27,300
%decrease in costs	8.90%	5.43%	6.21%
Computations			
Deviation	1.23	1.38	1.52
CPU	3,240	4,852	4,095
l1 -iterations	32.4	47.06	41.43
l2 -iterations	6.40	7.80	11.20
Total steps	2,289.1	3,412.4	3,210.2

If we look at the performance of the solution procedure we see that the time, on average, to calculate this variant is 3240 seconds (56 minutes). The number of iterations it takes to find the optimal capacity-assignment (*l1*-loop) is on average 32.4, consuming quite some time. Within the second inner-loop (*l2*-loop), the implications of the then current network configuration and use of the assets on the asset-specificity of the consortium partners and potential participants is calculated (on average 6.4 iterations). The development path of this network consists of 2289 steps and starts with a network that yields a cost reduction of 2.8%, the final network yielding a cost reduction of 8.9%. The development path of this particular variant showed that although the throughput in pallets increases rapidly along the development path, the total cost reduction remains around 2.5%. These large volumes do not really contribute to the cost reduction, but are essential for the feasibility of the network. Then, when the scope of the hub-network increases through additional hubs and sequences, the cost reduction increases. It can be argued that it is therefore very difficult to implement this network because it takes quite some time and investment before the real benefits can be achieved.

In the second and third variant transaction costs are incorporated in the optimization of the network. We distinguish two variants: high transaction costs (δ^{tc}_{high}) and low transactions (δ^{tc}_{low}), the difference being higher search, bargain, and enforcements costs (+50% higher hourly rate). When we introduce the high transaction costs the total network costs, derived from the network optimization, are €170,435,500, a total cost reduction of €6,382,500, a cost reduction of 5.4%. This result is considerably less than the LB-variant presented above. The transaction costs of all participants add up to €2,434,500, on average €54,100 per participant. The manufacturer makes most of these transaction costs due to the fact the manufacturers govern this network and can search, contact, and bargain with the carriers, inland carriers, and terminal operators (Figure 8-7).

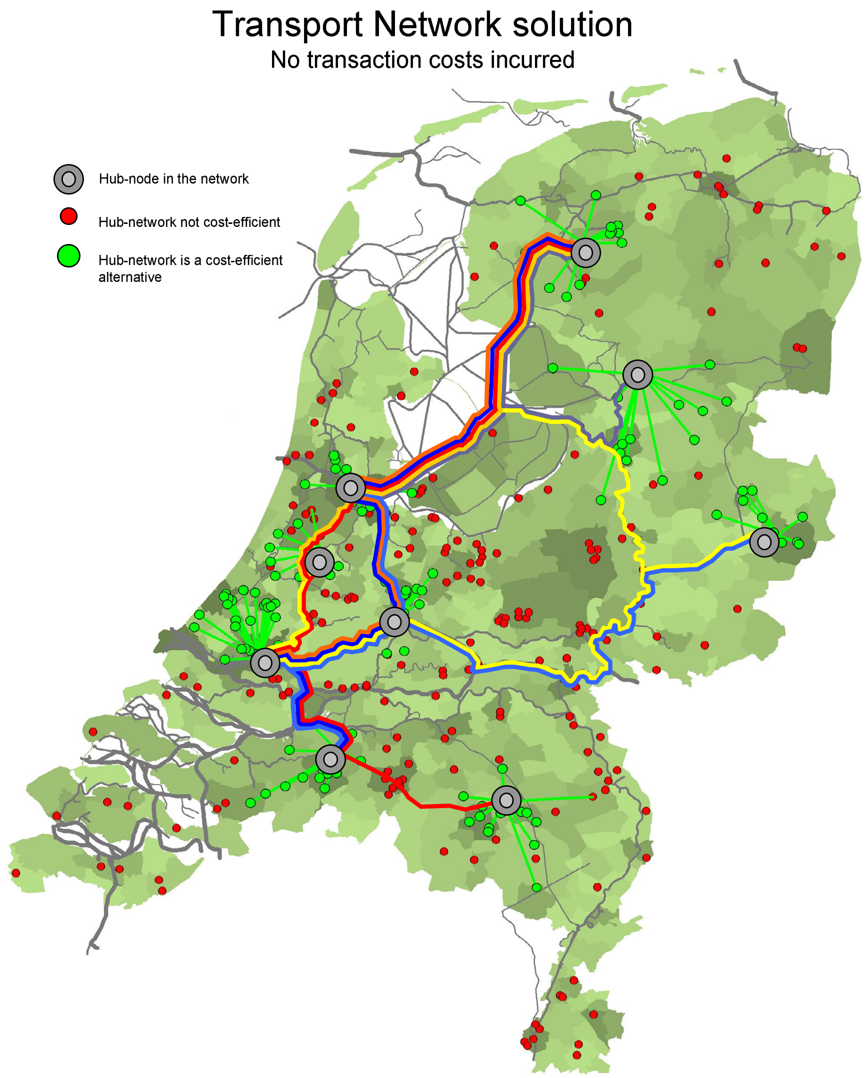

Figure 8-14: *Transport Network* stage solution with no transaction costs or additional resistances incurred.

The number of sequences is reduced to 4 and the capacity deployed is 20 barges. The total volume shipped through the hub-network is 1,382,000 with the average costs per pallet of €16.10. In comparison with the LB-variant this means a reduction in the volume of 44%, and, more importantly, a cut in estimated cost reduction of 56%. Figure 8-14 depicts the lower-bound network solution with the different hubs and sequences. Next to the hubs and sequences, the participants and other actors are illustrated. The green circles denote the locations of the participants that make use of the hub-network, the hub to which the location is assigned is denoted by a green line.

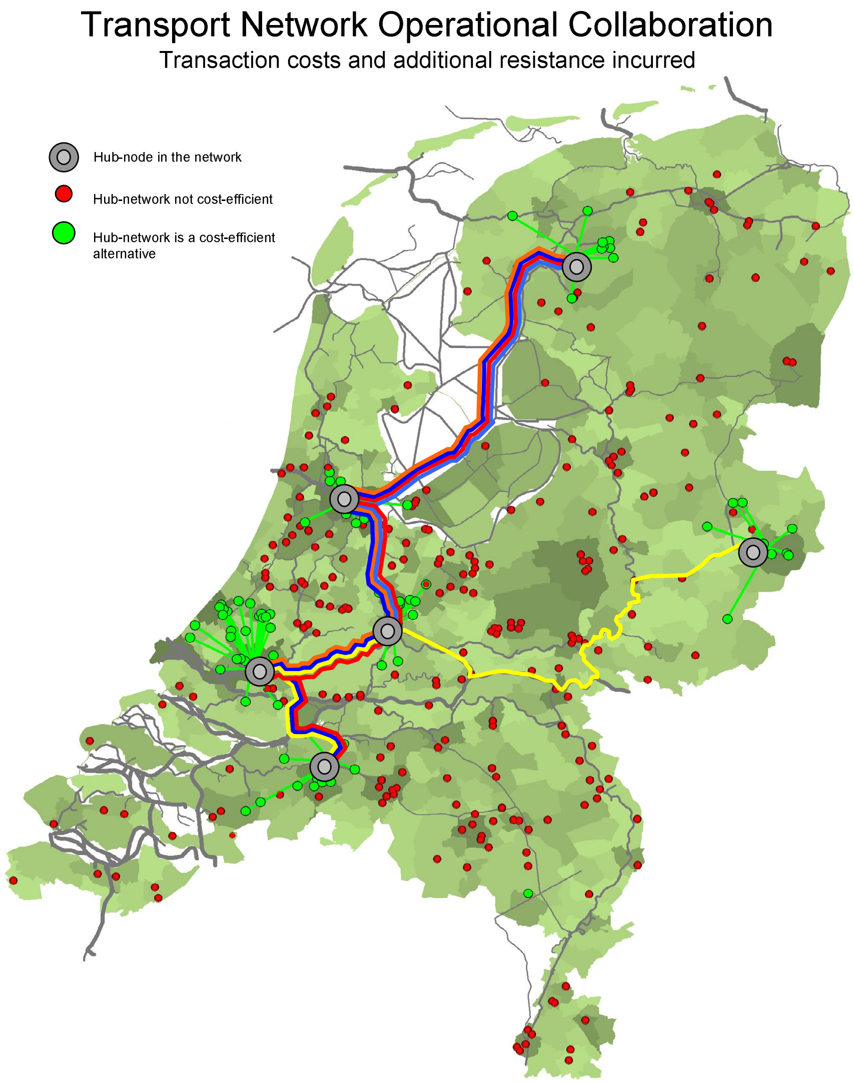

Figure 8-15: *Transport Network* solution with high transaction costs and additional resistances incurred (δ^{tc}_{high}).

The locations for which the hub-network is not a cost-efficient alternative are denoted by the red circles. Next to the network solution for the lower-bound, the network solution of the variant with the high transaction costs is presented (Figure 8-15). This network consists of four sequences and only 6 hubs. Again the participants are denoted by the green circles. If we look at the differences between the two variants in detail, it shows that the network solution, in terms of hubs and sequences is, structurally different and fewer actors decide to participate in the collaboration. Figure 8-16 presents a pivotal result of this scenario. In this figure four different actors are distinguished.

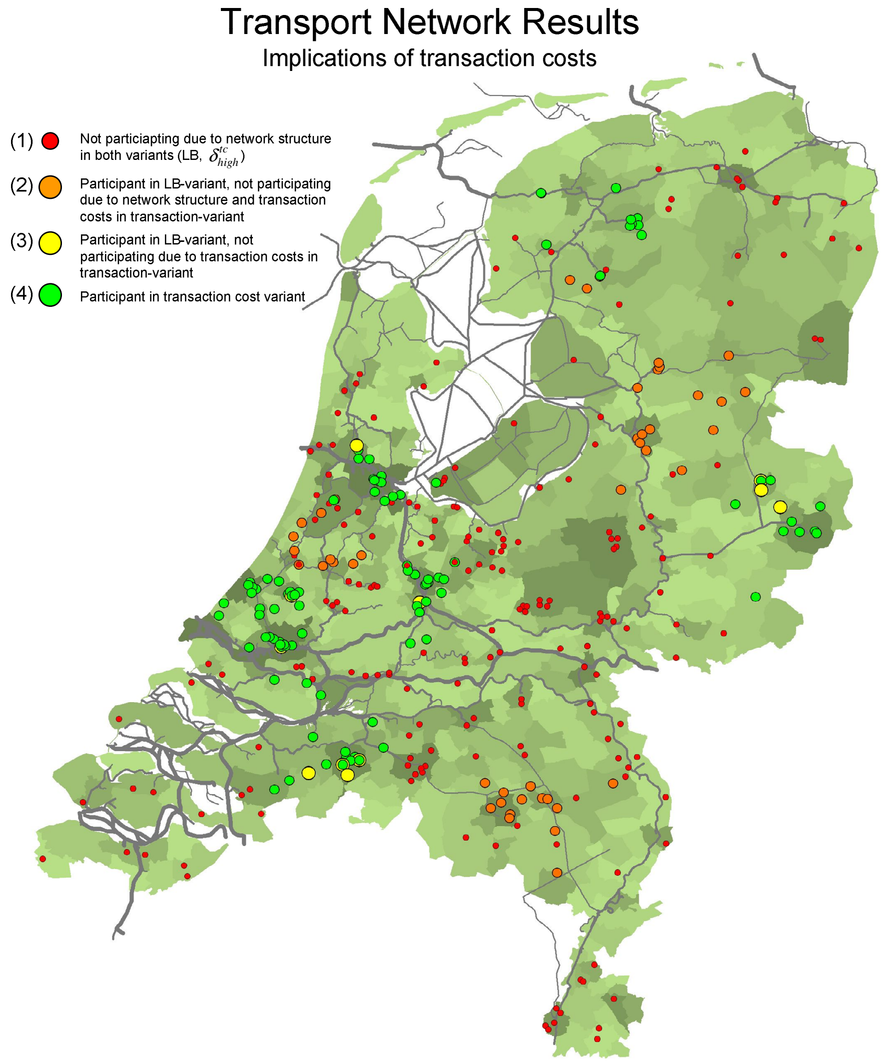

Figure 8-16: The excluded participants due to the introduction of transaction costs and additional resistance (δ^{tc}_{high}).

These four are: (1) actors that do not participate in the lower-bound and transaction costs variant, (2) participants that participated in the lower-bound variant but due to the changed network structure and incurred transaction costs will no longer participate, (3) participants in the lower-bound variant, but due to the incurred transaction costs will no longer join, and (4) the participants that participate in both network variants. These four types of actors are depicted by colored circles in the figure above (see legend). The difference between types (2) and (3) is that in the former, the actors discard the network structure solely based on the integral costs, excluding the transaction costs, and in the latter the network structure is assessed to be cost-efficient but due to the incurred transaction costs the actors decided not to participate. It can be concluded that, even the conservative estimation of the transaction costs has a significant effect on the network structure, total throughput and the total costs reduction in this scenario. In total 79 companies participated in the lower-bound variant, in the transaction costs variant (δ^{tc}_{high}) only 45 remained.

8.3.2 The Distribution Network, *Coordination collaboration*

The second stage is the *Distribution Network*, a *Type II* collaboration. In total 26,310, 000 pallets annually are transported in the starting situation, again all by truck. The average cost/pallet is €13.12. The total network costs before optimization are €387,066,000. Using the network design methodology the lower-bound solution of this scenario can be derived (LB), with no transaction costs and additional resistance incurred. Table 9 presents the overall results of the network optimization of the *Distribution Network*.

Table 9: Results of the hub network design procedure: Distribution Network.

	Results of optimization		
Variable	LB-network	High Transaction costs	Low Transaction costs
Network Structure			
%total flow through hub	18.51%	12.58%	15.49%
Total volume	4,870,000	3,270,000	4,028,000
Number of participants	144	70	105
Number of sequences	9	5	7
Capacity deployed	45	25	35
Performance			
Total cost	€341,328,000	€369,072,000	€359,887,000
Total Transaction costs	€0	€5,831,000	€4,599,000
Total cost reduction	€45,738,000	€17,994,000	€27,179,000
Average costs /pallet	€15.65	€19.49	€17.48
Average transaction costs	€0	€83,300	€43,800
%decrease in costs	13.40%	6.98%	9.31%
Computations			
Deviation	1.28	1.44	1.41
CPU	3,360	4,978	3,796
I1-iterations	35.3	17.06	21.43
I2-iterations	7.43	7.98	6.90
Total steps	2,710.8	1,650.0	2,142.0

The total network costs are € 341,328,000, a reduction of €45,738,000 (-13.4%). In total 11 sequences are included in this network solution. In Figure 8-17 these 11 sequences are depicted. The number of barges deployed (with a capacity of 600 pallets) on these sequences is 55. The average costs for shipping a pallet through the hub-network is €13.5. The volume accommodated by the hub-network is in total 4,870,000 pallets, 18.5% of the total annual volume. The network comprises 12 hubs and again each sequence includes 4 or 5 hubs with 6 to 7 barges being deployed in sequence in the final network solution. The cycle times in the final network solution vary between 6 hours (time between two consecutive barges) and 12 hours. Figure 8-17 depicts the lower-bound network solution with the different hubs and sequences. Next to the hubs and sequences, the participants and other actors are illustrated.

Figure 8-18 presents an overview of the different actors: (1) actors that do not participate in the lower-bound and transaction costs variant, (2) participants that participated in the lower-bound variant but due to the changed network structure and incurred transaction costs will no longer participate, (3) participants in the lower-bound variant, but due to the incurred transaction costs will no longer join, and (4) the participants that participate in both network variants.

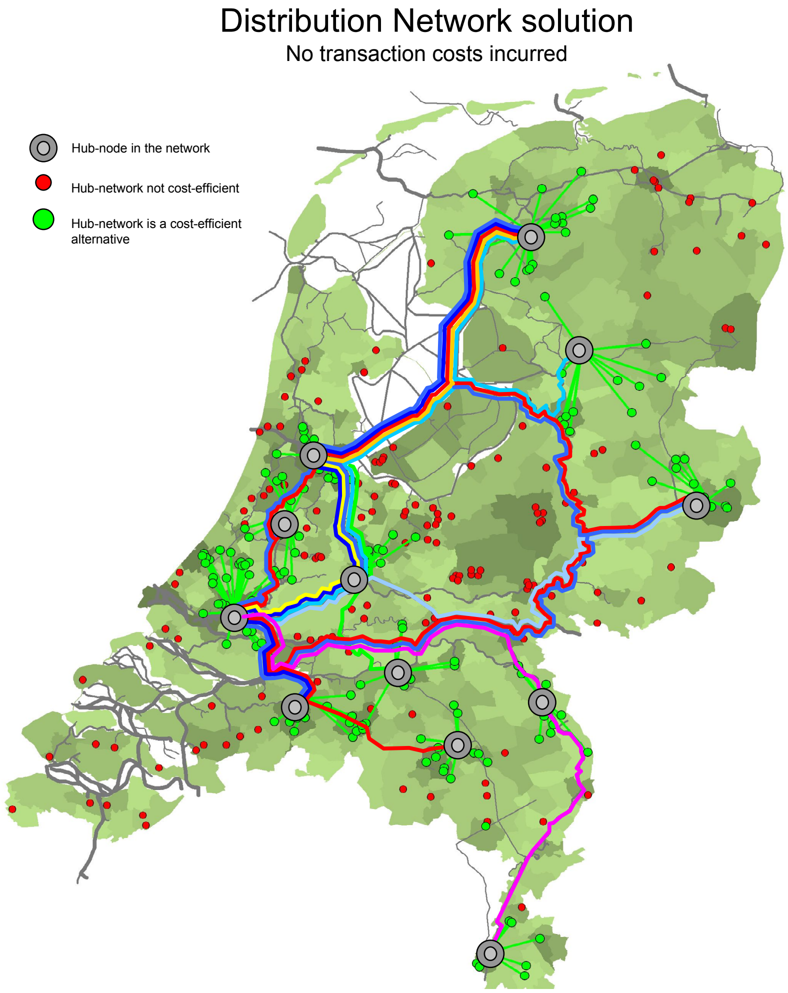

Figure 8-17: *Distribution Network* solution with no transaction costs and additional resistances incurred

The green circles denote the locations of the participants that make use of the hub-network, the hub to which the location is assigned is denoted by a green line. The locations for which the hub-network is not a cost-efficient alternative are denoted by the red circles. In the transaction cost-variant (δ^{tc}_{high}) 84 participants joined the network, a reduction of 52%. Due to the different network structure (no hubs in Venlo, Den Bosch, Lemmer) 21% of the participants of the lower-bound-variant no longer joined the network. Due to the incurred transaction costs, 30% of the former participants no longer joined the network (depicted by the yellow circles). In total a cut of 63% in cost reduction is the result of the introduction of the high transaction costs.

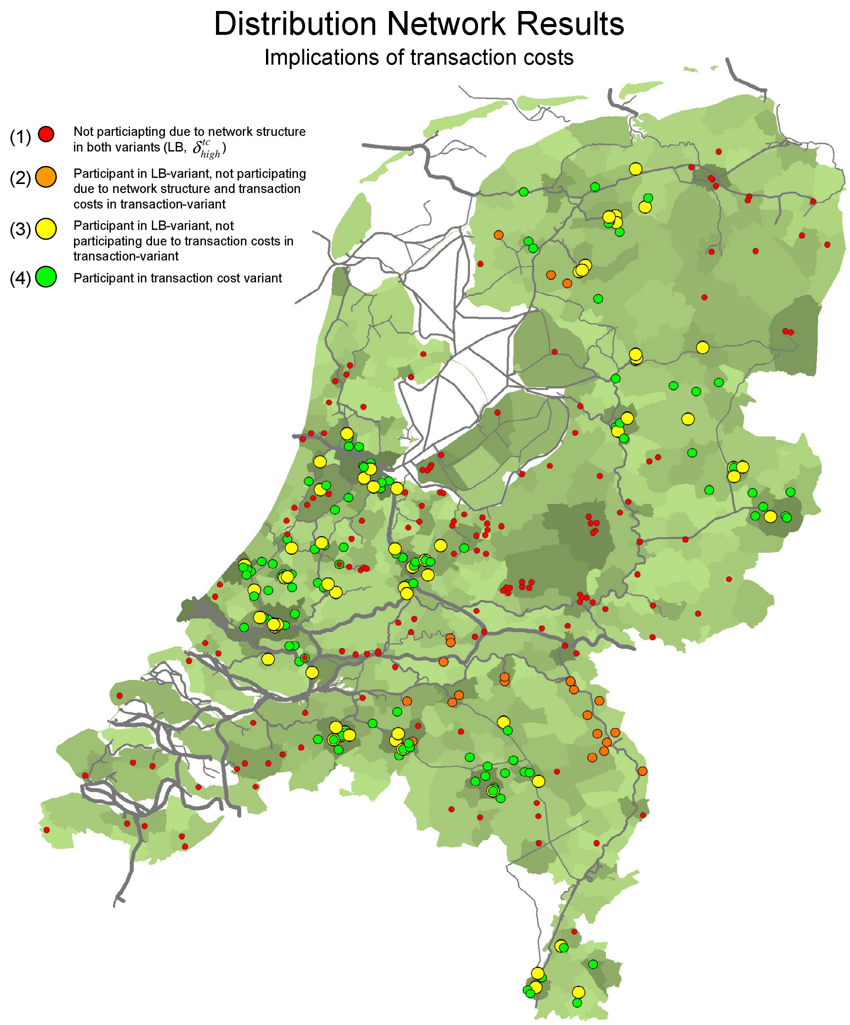

Figure 8-18: The excluded participants due to the introduction of transaction costs and additional resistance (δ^{tc}_{high}).

Table 9 presents the results of the variant with low transaction costs. It can be concluded that if transaction costs are introduced, even minor transaction costs, the impact this has on the network structure and performance is tremendous (whether they are high or low). The fact that more actors decide not to join the collaboration because of the transaction costs in this scenario, can be explained by the fact that the shipment volumes on the origin-destinations in this scenario are smaller and, although the average costs per pallet are higher, the number of pallets to pass on the transaction costs are less.

8.3.3 The Collaboration Network, *Network Collaboration*

The third stage we discuss is a *Type III* collaboration referred to as the *Collaboration Network*. The impact of this form of collaboration on the governance structure and daily operations is by far the greatest of the three scenarios. In this scenario, it is assumed that economies of scale can be achieved in transportation but also, through collaborative planning, in inventory and administration costs. To implement this collaboration the investments are considerable, not only for the manufacturer and service provider, but also for the retailer, yielding high asset specificity and transaction costs for all actors involved. Table 10 presents the results for the three variants: the lower-bound, high transaction costs, and low transaction costs.

Table 10: Results of the hub network design procedure: Collaboration Network

	Results of optimization		
Variable	Optimal network	High Transaction costs	Low Transaction costs
Network Structure			
%total flow through hub	12.41%	7.40%	9.45%
Total volume	3,265,000	1,923,000	2,457,000
Number of participants	112	56	78
Number of sequences	9	5	7
Capacity deployed	45	29	35
Performance			
Total cost	€330,328,000	€367,021,000	€358,253,400
Total Transaction costs	€0	€12,712,000	€10,748,400
Total cost reduction	€54,834,000	€18,141,000	€26,908,600
Average costs /pallet	€13.65	€16.65	€13.65
Average transaction costs	€0	€227,000	€137,800
%decrease in costs	16.60%	9.34%	11.40%
Computations			
Deviation	1.28	1.24	1.22
CPU	3,360	4,810	3,379
I1-iterations	39.3	17.06	21.43
I2-iterations	9.40	8.21	7.43
Total steps	2,710.8	1,914.0	2,142.0

In the lower-bound variant the total network costs are €330,328,000, a cost reduction of €54,834,000 (-16.6%). The number of sequences in this network is 9, connecting 7 hubs with each other. The number of participants in this network is 112 and the total volume accommodated by this network is 3,265,000 pallets per year. The average cost per pallet is €13.65. If we look at the transaction costs in the three variants presented in the table above we see that these costs have increased considerably compared to the two scenarios before (Table 8 and Table 9). This is primarily caused by the increased complexity and search costs.

In the lower-bound variant, despite the required investment in information systems, equipment and barges, the number of participants is relatively high (112). In both the transaction cost variants this number drops to 56 and 78 respectively, a considerable reduction of participants, volume and total cost reduction. The total transaction costs are €12,712,000 and €10,748,400, on average €227,000 and €137,000 per participant. The total decrease in costs in the lower-bound variant is 16.6%, and even with the reduction in the number of participants, the reduction of the total network costs is relatively high in both transaction costs variants (9.3% and 11.4%). In Figure 8-19 the network solution, derived from the network design phase, for the lower-bound variant is presented. In this figure the 9 sequences and 7 hubs are presented. In total in the lower-bound variant 45 barges are deployed, in the variant with high transaction costs (δ^{tc}_{high}) in total 29, and finally in the variant in which low transaction costs are incurred 35. Figure 8-20 presents the implications of the transaction costs (δ^{tc}_{high}) on the actors' decision to participate in the hub-network. Again five different types of actors, included in the network design are distinguished. In the lower-bound variant 112 participants join the network sending a volume of 3,265,000 pallets through the network per year.

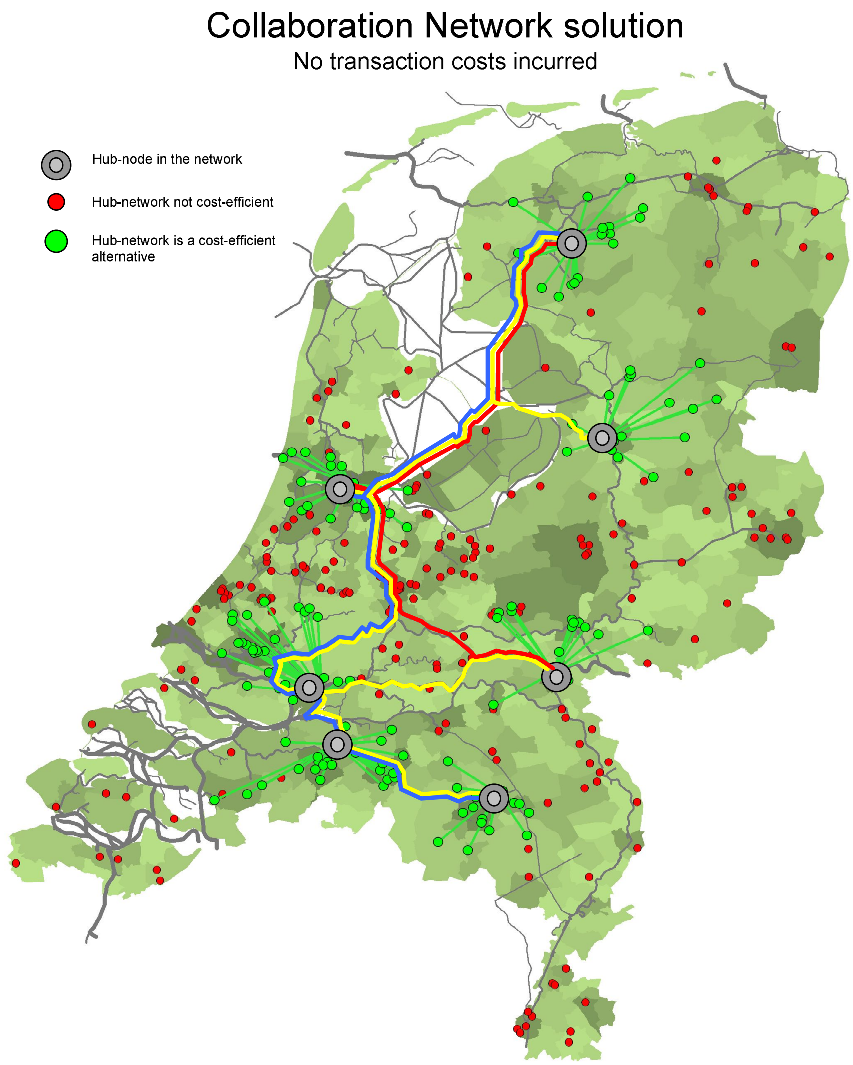

Figure 8-19: *Collaboration Network* solution with no transaction costs and additional resistances incurred

Due to the changed network structure (after the introduction of the transaction costs, δ^{tc}_{high}) 26% of the participants decide not to join because of the new network structure, resulting in higher logistics costs, excluding the transaction costs. An additional 28% of the former participants decide not to join the new network because of the transaction costs, even though the new network structure is cost efficient in terms of the integral logistics costs (costs per pallet) compared to direct shipment. The results show that the introduction of the transaction costs has a major impact on both the decision to participate and the network structure and, even though the introduced costs were estimated conservatively, the impact of both levels of transaction costs is significant, especially in the *Distribution* and *Collaboration Network*.

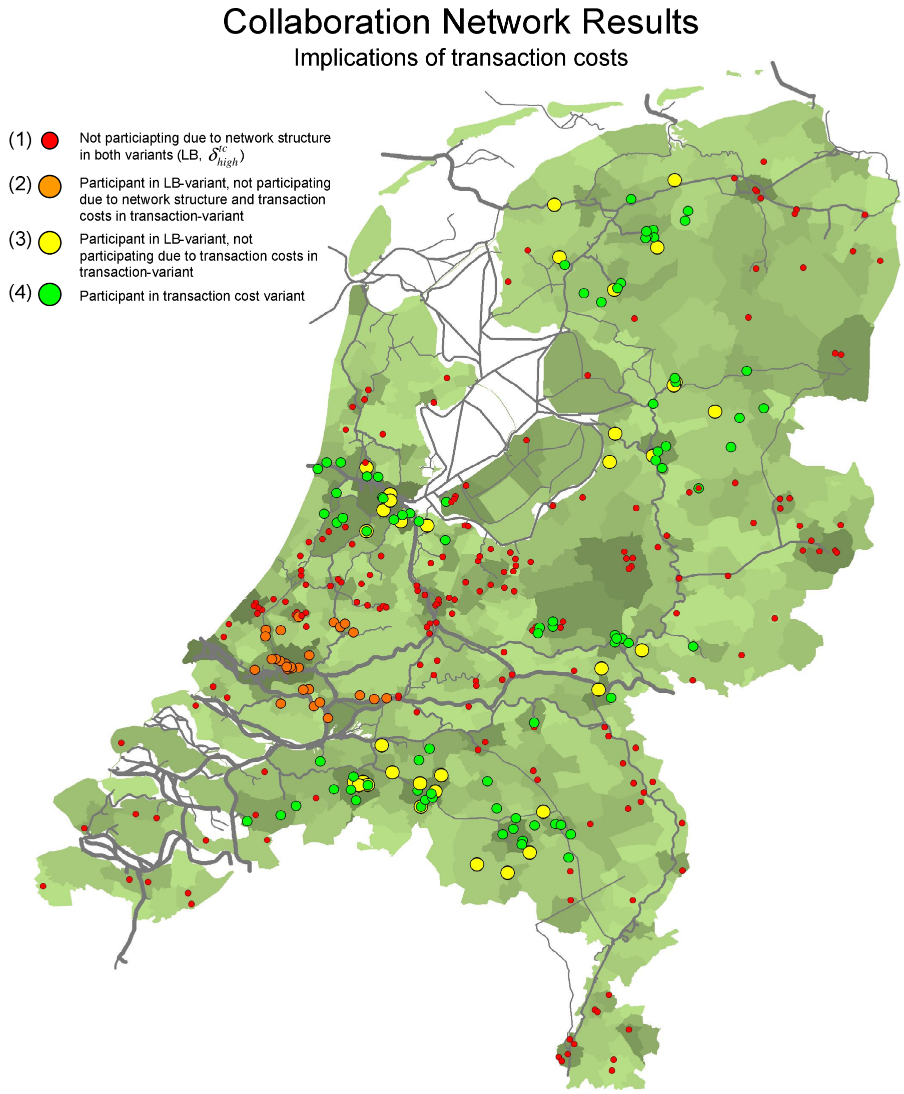

Figure 8-20: : The excluded participants due to the introduction of transaction costs and additional resistance (δ^{tc}_{high}).

8.4 Evaluation of the designed networks

After the network design phase we used simulation (step 4 Figure 8-1) to assess the network solutions, derived from the network design phase. Based on the information provided by the focus group we were able to simulate the different hub-networks solutions and assess the performance of these solutions in terms of costs, robustness, and reliability.
During these simulations the network structure of the companies involved was implemented (locations, volumes, orders, shipments, inventory, dispatches, etc.) and the starting situation was then simulated to derive the current costs per pallet and total logistics costs. These costs, shipments, orders, and inventory positions could then be validated using the performance information provided by these same companies.[34]

The methodology proved to be sufficiently accurate to be used to represent the costs in the current situation and deriving the costs in the hub-network. The next step was to implement the new network solutions in the simulation and simulate the same orders. The costs and other performance indicators we derived from the simulation were then compared with the costs accompanying the network design. These simulations were carried out for the individual companies and the results were presented separately. As these results are confidential and not necessary to present here, we will only present some general conclusions. For additional information on the simulation of the network solutions we refer to Groothedde *et al*. (2003). Once the members of the focus group were convinced of the validity and accuracy of the simulation model and simulation of their logistics structure, different network scenarios were tested.

Key issues that were addressed during the simulation were the fraction of the flow send via the hub network, the inventory strategy to be used, the lead-time reliability, and transshipment capacity at the hubs. The fraction of the flow send through the hub-network $(1-\theta)\cdot q_1$ was tested using simulation. It varies a great deal among the different members of the focus group, varying between 40% and 67% of the volume. If the fraction $(1-\theta)\cdot q_1$ is too low the utilization of the assets in the hub-network is low, if the fraction is too high orders can not be fulfilled due to the extended shipment lead-time. Another key aspect that was tested extensively is the inventory strategy; should an intermediate storage be used located at the hub or not and what is the consequence of this temporary storage on the logistics costs, the lead-time, and reliability of the network? Including this intermediate storage has an increasing effect on the costs but makes it possible to react very quickly to the customer order, hereby shortening the lead-time and increasing reliability.

Another critical aspect of the concept that was extensively tested was the transshipment capacity on the hubs. This proved to be a critical aspect that heavily influenced the cost efficiency of the hub-network concept. In addition, the simulation allowed us to test a range of operational aspects. The FIFO (*First-In-First-Out*) principle in the supermarkets is very important and when using the hub-network and direct shipment next to each other, the possibility arises that products with a later expiry date 'overtake' products with an earlier

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[34] An impression of the accuracy achieved is provided by the comparison of the calculated and actual the carrier rates provided by the focus group in Appendix G: Overview of the cost components. These calculated costs were based on the travel-times, distances, routes, loading and unloading times derived from the simulation.

date. Likely, products will be rejected at the warehouse of the retailer. Using simulation we were able to estimate the magnitude of this specific problem. Another operational issue that was addressed was the compliance with the time windows at the retail warehouses. Is it possible to comply to these restrictions, set by the retailer, when using the hub-network, and if not, should the time window be relaxed, or should there be made use of an intermediate storage? During the simulations phase all types of question were addressed leading up to a better understanding of the strong and weak points of the concept. This phase, of evaluating the network solutions, has proven to be critical and valuable in the acceptance of the concept and network solutions (Groothedde *et al*. 2002).

8.5 Implementation of the networks

The design and evaluation framework was developed to support the implementation process of a collaborative logistics network. Although the focus of dissertation is on the design and evaluation using different modeling techniques, the capability to delineate the development path of these networks, implement different scenarios, and assess the feasibility, forms an indispensable part of the research. During the *Distrivaart* project the methodology was used to support the decisions on the network structure and feasible pilot networks.

Between September 2002 and June 2003 the first dedicated pallet barge *Riverhopper* was deployed in a pilot project to test the loading and unloading of the pallets, the shipment times, reliability and the costs per pallet. During this first test phase the pallets were transshipped using forklifts and a single sequence per week was completed, loading and unloading pallets in Drachten, Zwolle, Den Bosch, and Oosterhout. Four manufacturers (Bavaria, Heineken, Grolsch, and Interbrew) and four retailers (Albert Heijn, Schuitema, Super de Boer, and Laurus) were involved. Coca Cola joined in February 2003.

The second phase of the pilot was executed between February 2003 and October 2003. During this second phase, the focus was on the logistical and technical aspects of the concept. This phase was successfully executed and in June 2003 the barge was equipped with a fully automated pallet handling system. The loading and unloading capacity was hereby doubled, making a second sequence in the single week possible, making the concept more competitive. On November 4th 2003 the concept won the European Intermodal Award of the European Intermodal Association and was launched as a commercial pilot by logistics service provider Vos Logistics and barge operator Riverhopper in January 2004. Manufacturers Bavaria, Interbrew, Coca Cola, and Grolsch and retailers Albert Heijn and Schuitema participated. However, at the end of 2004 the *Distrivaart* initiative was ended because the utilization of the barge was structurally too low. It can be argued that the *Distrivaart* concept, as proposed was never actually tested because only a single barge was deployed, thus never really achieving the necessary economies of scale.

During the commercial pilot carriers and service providers acting on behalf of the manufacturers and retailers were bargaining for a better transport rate and were comparing direct shipment rates and the rates offered by the hub-network. The concept Distrivaart was simply not mature enough to withstand this opportunistic behavior. The participants, manufacturers and retailers were reluctant to proceed with the commercial pilot and the potential partners were not willing to switch, either due to the high transaction costs in relation to the projected benefits or they decided to wait until Distrivaart was proven technology. In order to achieve substantial benefits additional volume was needed, to start the true concept, as it was proposed by Vermunt (1999). But as witnessed by the development path of the *Transport Network*, the scenario closest to the commercial pilot, is very difficult to 'start up' (see Figure 8-21). In the beginning of the development path of this network the benefits are very low and it is not until the capacity in barges is extended and the number of sequences is increased that the cost benefits may become substantial. Especially, if we take into account the very competitive rates of the trucking carriers are able to offer. It is not until the network consists of four hubs and five barges that the cost decrease in an upwards direction and the economies of scale are achieved. What we witnessed in the Distrivaart project was that this long-term outlook of the participants was not present, and this being absent it became a competitive setting.

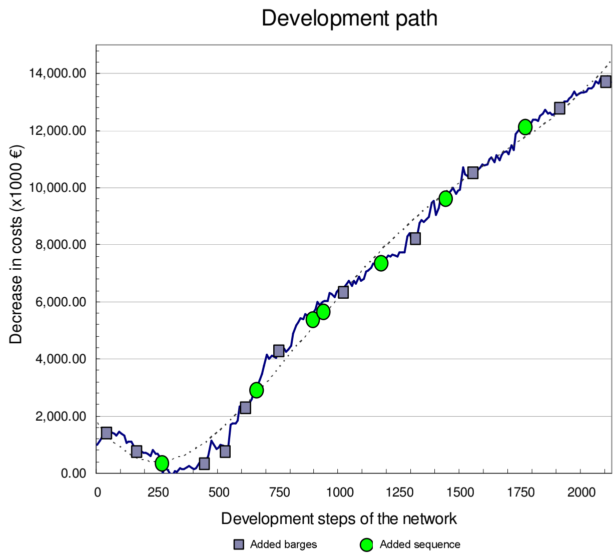

Figure 8-21: Overview of the development path of the *Transport Network*.

9 Conclusions and recommendations

The evolution of logistics networks during the last decades can be characterized by a strong rationalization of business processes. Companies have become more aware of the impact that their logistics organization can have on the costs of doing business and on the degree of satisfaction of their customers. This ongoing rationalization has led to a constant search for economies of scale in the supply chain, which has been an important parallel development in line with the changes in globalization and manufacturing.

A strategy that has become more and more apparent is seeking collaboration with partners in order to achieve the necessary scale and scope to meet the customer demands. The difficulty when searching for such a partnership in logistics is finding the most appropriate scope, type and form of collaboration. Even more so because the impact of a partnership or collaboration on the logistics organization, governance structure, number of facilities, inventory policy, etc. can be far-reaching, both in time and costs. The decision to seek an in-house solution, outsource or participate in a collaborative network is one of the key decisions in business, and also in this dissertation. The decision to participate in a collaborative network always be seen in perspective with other options open to the firm (e.g. outsourcing, in-house solution or extension of the current solution) and becomes more and more relevant with the introduction of partnerships, CPFR, JIT and the concept of collaboration in logistics.

The main motivation behind the tendency to look for collaboration between partners in logistic networks is to achieve economies of scale and scope. Through the combination of activities it is possible to share costs, through sharing information it is possible to avoid unnecessary costs and through avoiding sub-optimization and acting as one organization the business units that co-operate can work more efficiently and become more effective at the same time. By collaboration companies can achieve: (1) *Asset or Cost efficiencies;* a potential for cost reduction provides a strong reason to partner, (2) *Customer service;* integrating activities in the supply chain through partnerships can often lead to service improvements for customers in the form of reduced inventory, shorter lead-times, and more timely and accurate information, (3) *Marketing advantage;* a third reason for entering into a partnership is to gain a marketing advantage, and (4) *Profit Stability or Growth;* a potential for profit improvement is a strong driver for most partnerships. These relationships between organizations can range from arm's length relationships to complete vertical integration of the organizations. It is evident that a decision concerning the structure of the logistics network, for example the number of warehouses in the network, influences the inventory policy, and transport planning. To understand these inter-dependencies between the different levels of decision-making in logistics the use of models is essential.

The myriad of relations and interactions between the actors operating in the logistics network poses structurally complex network design problems to each of the organizations individually and to the network as whole. We presented a modeling framework to support the network design decision and make it possible to analyze the implications of the different types of collaboration on the network structure, alignment, scheduling, and resource deployment. The key aspects we considered are:

(1) *Scope and Objective of the collaboration;* based on the hierarchy in decision-making the scope of the collaboration is the structure of the network, the alignment, the scheduling or the resource deployment). The objective of the collaboration is either *asset or cost efficiencies*; customer service, marketing advantage, or *profit stability or growth*.

(2) *Type of collaboration*, we distinguish three types of collaboration; *Type I, operational collaboration*, usually focused at cost and asset efficiency; *Type II, coordination collaboration*; and *Type III, network collaboration*.

(3) *Asset specificity*, in any collaboration the asset specificity for the participants is a key determinant. It is therefore necessary, when modeling the choice-behavior, to gain insight into the asset specificity for all actors.

(4) *Uncertainty,* a second important determinant is uncertainty and a key determinant of the height of the transaction costs (and hereby influencing the choice-behavior substantially).

(5) *Frequency*, the third contingency in *Transaction Costs Analysis,* is the frequency of occurrence. This is considered an important attribute, from the point of view that the costs of specialized, expensive, governance structures will be easier to recover for large transactions of a recurring kind.

(6) *Dominance*, reflects its potential for influencing the actions and decisions of individuals and firms in the network.

(7) *Transparency,* refers to the trust among the participating actors and the measurability of the costs, benefits, performance, etc..

Based on these 7 aspects we classify the different collaborations and translate the scope, objective and contingencies into model parameters, allowing us to estimate the impact of the type of collaboration on the transaction costs and decision-making process dealing with collaboration, and the logistics network design.

In the following sections we will discuss our main message, based on the outcomes of the case study and will present the implications of introduction of the transaction costs for the network design. In section 9.20 we will summarize the research findings. We will elaborate on the feasibility of the network solution found when optimizing, the modeling framework, and the ability to delineate the development path. In section 9.3 we focus on the methodological implications of the research presented in this dissertation. Issues we will discuss are the collaboration typology; the incorporation of transaction costs in logistics network design; the comprehensive modeling approach, including network design and simulation; the hub-network design optimization methodology; and the network development capability. Finally, in section 9.4 we will discuss the recommendations for further research.

9.1 Main message

The main message of the dissertation is that it is possible to design collaborative logistics networks based on the integral logistics and transaction costs, and using our modeling framework makes it possible to assess ex-ante their potential performance. The drivers mentioned in the introduction of this chapter provide the motivation to partner and seek collaboration. But even with a strong desire for building a partnership or joining a collaboration, the probability of success is significantly reduced if neither of the corporate environments is supportive of a close relationship. On the other hand, a supportive environment which enhances integration of the two parties will improve the success of the partnership. We deliberately start by mentioning this key aspect in collaboration and hereby putting network design and evaluation into perspective. Designing and evaluating these networks, even with sophisticated tools, is only a piece of the puzzle. Symmetry, in terms of the importance of each firm to the other's success, compatibility and transparency are as important for the successful implementation of collaboration as being able to design and evaluate the different network solutions.

When developing collaborative networks it has proven to be crucial to incorporate the transaction costs and additional resistances. Already during the network design process these costs, based on the type of collaboration, should be taken into account. As the decision to participate is highly influenced by these costs and the impact on the network structure can be far reaching, it is important to be able to distinguish between feasible and non-feasible network solutions at an early stage. Whether or not the transaction costs are high or low, the impact of these costs on the structure of the network is high. It is therefore imperative for the all actors (inside and outside the consortium) to be able to choose a collaboration strategy, decide on the type of collaboration and, given the scope, objective, asset specificity and other characteristics, be able to gain insight into the accompanying transaction costs and feasibility of the network solutions. It is important to be able to make the assessment, not only because of the implications for one's own transaction and logistics costs, but because in a collaborative network the structure of the network and the costs of all the individual companies are influenced by its partners as well.

It is evident that a decision concerning the structure of the logistics network, for example the number of warehouses in the network, influences the inventory policy and transport planning. To understand these inter-dependencies between the different levels of decision-making in logistics, the use of models is essential. The capability to calculate and design these networks is very important. Combining these with evaluative tools is very valuable, especially in collaborative logistics, where transparency and measurability are decisive.

To support this highly complex decision-making process we developed a comprehensive modeling framework in which we focused primarily on two different classes of models: (1), *the network optimization models*, and (2) *the network simulation models*. The former, used to design and optimize logistics networks, and the latter, to evaluate different network designs and for *what-if* analyses. For companies to decide to collaborate it is crucial to understand the impact s of the different types of collaboration on the structure, alignment, scheduling and resource deployment of the logistics network. In addition, insight into and understanding of the sensitivity of the logistics network for contingencies like dominance, transparency and uncertainty is of vital importance. The comprehensive design methodology presented in Chapter 6, capable of calculating the logistics costs, the transaction costs, evaluate the network solutions, and delineate the network development is an important enabler in collaborative networks, but can not be seen separately from other activities in the collaboration building process, presented in Figure 9-1. This five stage model, adapted from Gardner *et al*. (1994), and extended with our framework for designing collaborative networks can be used as a guideline to *build* a collaboration.

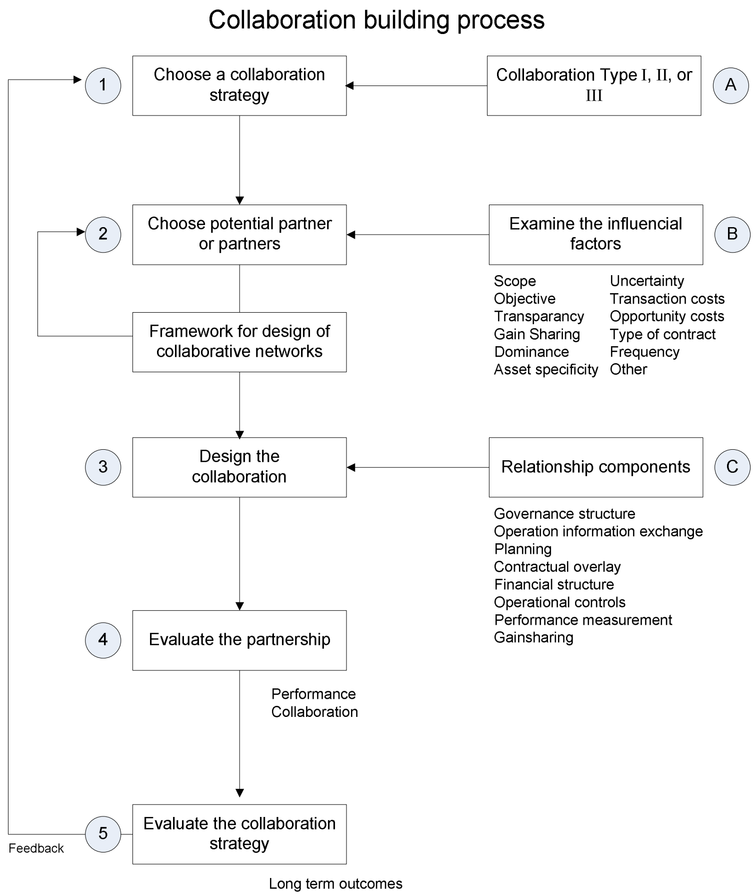

Figure 9-1: Steps in building a collaborative network

Firstly, a collaboration strategy should be formulated, in which the type of collaboration is chosen. The second step is to assess and select the potential partners. In searching and choosing a collaboration, a company should examine numerous potential influential factors and when using our framework, this step can be supported. A company or group of companies (consortium) can perform a targeted search for potential partners and the impact that their different characteristics will have on the network design, potential partners, and network performance can be illustrated.

Once the potential partners are found the collaboration should be formed, and during this phase a firm should consider different behavioral components, as well as contractual, financial, volume of business aspects, governance structure, etc.. The behavioral components include planning, gain-sharing, operational information exchange, and operational controls. The final step is formed by the evaluation of the collaboration strategy.

9.2 Research findings

The main objective of this study was to develop and demonstrate a design and evaluation methodology for logistics and transportation networks in which the participants collaborate. We found that the main logistics components, determining the logistics and transport network design, can be classified in motion, holding, handling and administrating activities. However, when designing collaborative networks it is necessary to include the transaction costs and additional resistances because these costs influence the network design significantly.

A hub-network is particularly suited for combining and consolidating the flows of different shippers and thereby achieve economies of scale. When using standardized load-units, the handling, sorting, and transshipment activities can be standardized and the investment can be kept economical. Consolidation in this types of network allow more efficient and more frequent shipping by concentrating large flows onto relatively few links between the hubs. Although use of indirect (that is via a hub) shipment may increase the distances traveled, the economies of scale due to the larger volume can reduce the total cost. These configurations can reduce and simplify network construction costs, centralize commodity handling and sorting, and allow carriers to take advantage of economies of scale. However, when the actors need to work together and take part in a collaborative hub-network, additional contingencies are introduced, leading to added complexity and constraints in the network design problem we are trying to solve.

Based on the literature survey, it was concluded that the existing network design and evaluation models were not sufficient. Instead of solely minimizing the total costs in the logistics network, or minimizing the costs of individual companies, when designing a collaborative network, we incorporated the scope of the collaboration and the type of partnership, and then include the implications of the type and scope of the collaboration on the network design.

We developed a comprehensive framework that is based on economic objectives such as minimizing the total costs, minimizing the user costs and the preferred levels of service set by these users. We analyzed collaboration in logistics networks and the impact the different types of collaboration have on the network design and performance in terms of costs, lead-time and reliability. The elements of a specific collaboration (for example the scope, objective, frequency, uncertainty, transaction costs, etc.) were incorporated in the network design procedure and it can be concluded that these aspects have a great impact on the network design.

The hub network design problem we focused on is a multiple assignment problem (customers can use more than 1 hub), combined with direct transportation. We introduced capacity restrictions on the hubs and on the inter-hub transfers. In addition, we incorporated transaction costs that influence the decision to participate in the hub network of the actors, based on the performance of the network solutions (e.g. costs, lead-time, and reliability). This design methodology, yielding feasible network solutions and development paths, is new and is a considerable extension on the current hub network design approaches. We introduced additional complexity but we were still able to find feasible network solutions and development paths.

When we compare the results of the network design when no transaction costs are incurred (lower-bound variant), the number of participants is relatively high. Introducing transaction costs changes the network structure and some participants then decide not to join this new network because of the higher logistics costs (excluding the transaction costs). This group of former participants is mostly affected by the changes in structure, not so much by the transaction costs themselves. But other former participants who decide not to join the collaboration, influence the network structure to such a degree that others decide to exit. An additional group of former participants may decide not to join the new network because of the transaction costs, even though the new network structure is cost-efficient in terms of the integral logistics costs (costs per pallet) compared to direct shipment. Even though the introduced costs were estimated conservatively, the impact of transaction costs is significant, especially in the *Distribution Network* and *Collaboration Network* scenario. When the consortium places restrictions on the development path of the network the development path ends sooner than for scenarios where no restrictions are placed. If the results of these network solutions are then compared with other scenarios in which no restrictions are placed on the path considerable differences in cost reduction can be observed: a considerable reduction in costs is not achieved due to the restrictions.

9.3 Methodological implications

The main objective of this study was to develop and demonstrate a design and evaluation methodology for logistics and transportation networks in which the participants collaborate. We analyzed the integral costs, the service requirements set by the users of the network, and the different types of collaboration and their implications on several characteristics. We tried to capture the key trade-offs in logistics influencing the logistics network design, the decision-making process in collaboration, and the development path of logistics networks.

We presented a new modeling framework in which we combined network design models, transaction cost analysis, and simulation techniques into a comprehensive approach. We extended the existing hub-network design models by introducing capacity restrictions on the hub, on the inter-hub transfer and incorporated service network design techniques.

To be able to design collaborative networks we developed a typology to classify different types of collaboration and identified the key elements of collaboration (the scope, objective, frequency, uncertainty, transaction costs, etc.). These were incorporated in the network design procedure. This makes it possible to elicit the impact collaboration has on the network structure and performance. In addition, we developed new perspectives on dominance in the logistics network and the influence of transparency, seen from a network design perspective. This allows the actors in the logistics network to assess the impact of dominant partners, trusting potential partners, and the influence of impact measurability, seen from the perspective of the specific actor, whether it be a retailer, manufacturer, service provider, or carrier. The collaboration typology helps the actors to position themselves in the actor network and assess the impact of the different types of collaboration on the costs and logistics performance. In the remainder of this section we will first discuss the methodological implications our modeling framework has on the design of a logistics network and how it can help manufacturers, retailers, or service providers in the search for feasible networks, followed by some specific implications our framework has on designing collaborative networks. The modeling framework makes it possible to design a specific logistics network from the point of view of a combination of actors, a consortium or a single service provider. In our dissertation we tried to optimize the network from the point of view of a consortium. However, it is possible to optimize from a specific point of view, delineating then different network solutions and their development path. It is even possible to search for those potential partners that will yield the highest added value for the consortium. This functionality is a primary innovation that we will illustrate using a realistic example.

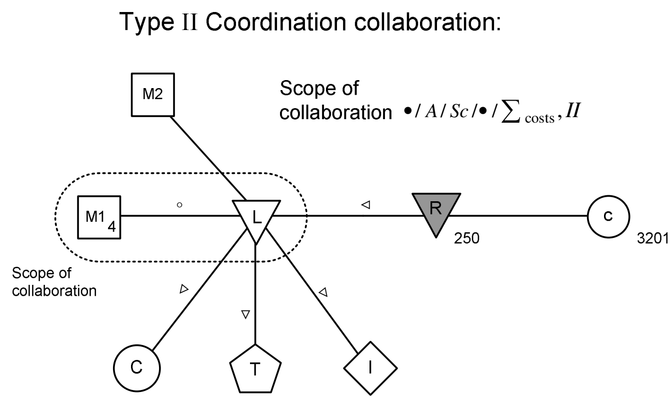

Figure 9-2: example of a collaboration between service provider and consortium of manufacturers ($M1_4$)

During the Distrivaart project several extensions and alterations were made on the three network types: *Transport*, *Distribution*, and *Collaboration Network.* In one such variant several key manufacturers joined a consortium and started a collaboration with a service provider, governing the hub-network and responsible for finding additional participants. In Figure 9-2 the structure of this collaboration is presented. We present this structure as this was thought to be the most feasible form of collaboration. If this collaboration is implemented and the network is designed, as presented in section 8.3 it is possible to calculate the total cost reduction that can be achieved. It is also possible to make an assessment of the added value a specific participant has, in terms of cost reduction, and gain insight into the key participants. In addition it is possible during the development of the network to focus on those potential participants that will yield the highest added value for the consortium when joining the network. And as time and money is of course limited, this would considerably lower the search costs (part of the transaction costs) and enhance the feasibility of these types of networks.

Figure 9-3 presents an example of such an overview. In this figure the current participants are denoted by the green circles and the key participants (with an added value of >€2,500,000) are indicated by a dark green circle. These are the key manufacturers that together form the consortium. The other participants are denoted by the green circle and their added value ranges from €250,000 - €2,500,000. A second category of actors is formed by the potential participants and, using the modeling framework, this group of actors can be identified at every step of the development path. For example, the presented overview lists the potential participants at the 6th step of the development path (5 hubs and 7 sequences are present).

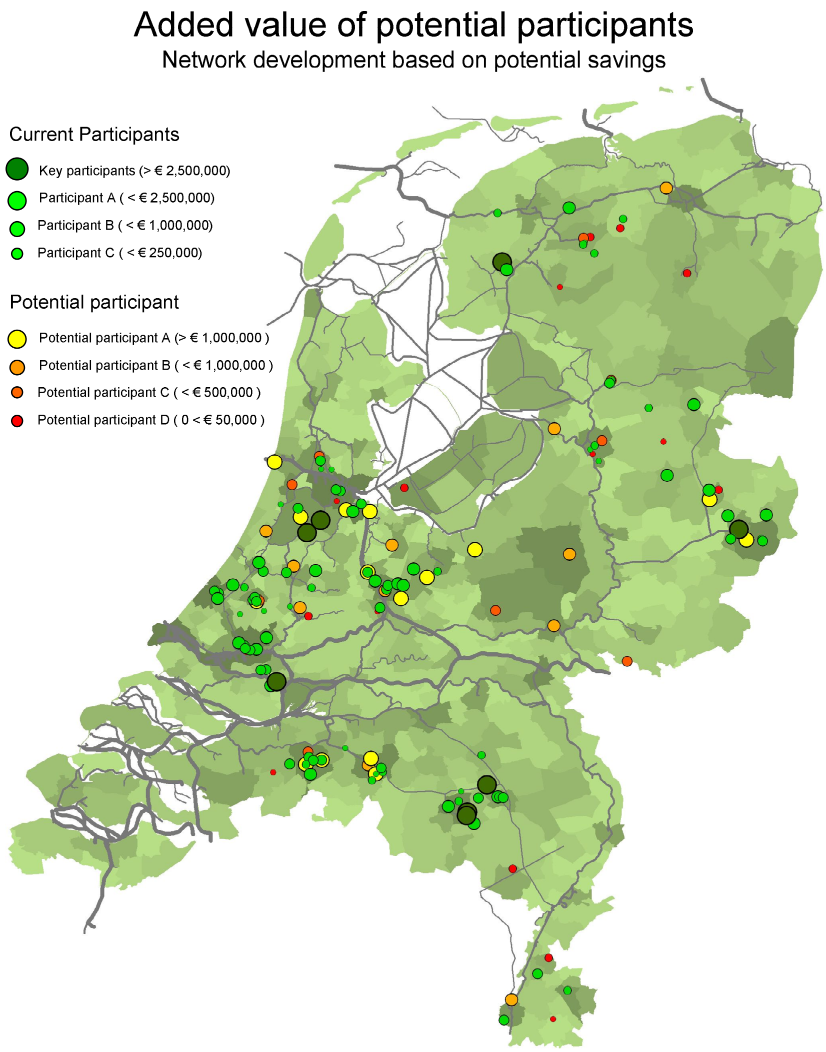

Figure 9-3: Overview of the current consortium and potential participants with an indication of the added value of the individual firms to the consortium.

This provides the opportunity to target those key participants, by the service provider or the consortium, to participate, knowing the added value this customer represents. For logistics service providers this methodology can help to target potential customers and instead of waiting for an *out-sourcing*-decision of these potential customers the service provider can actively approach these retailers or manufacturers, offering them a competitive quotation. That is what Cruijssen (2004) refers to this as *in-sinking*, the antonym of *out-sourcing*. If the added value is then combined with the service performance of the network (as presented in Figure 9-4) the trade-off between costs and services can be made. In this figure the proximity of the customer is illustrated that is possible if the hubs would function as a temporary storage.

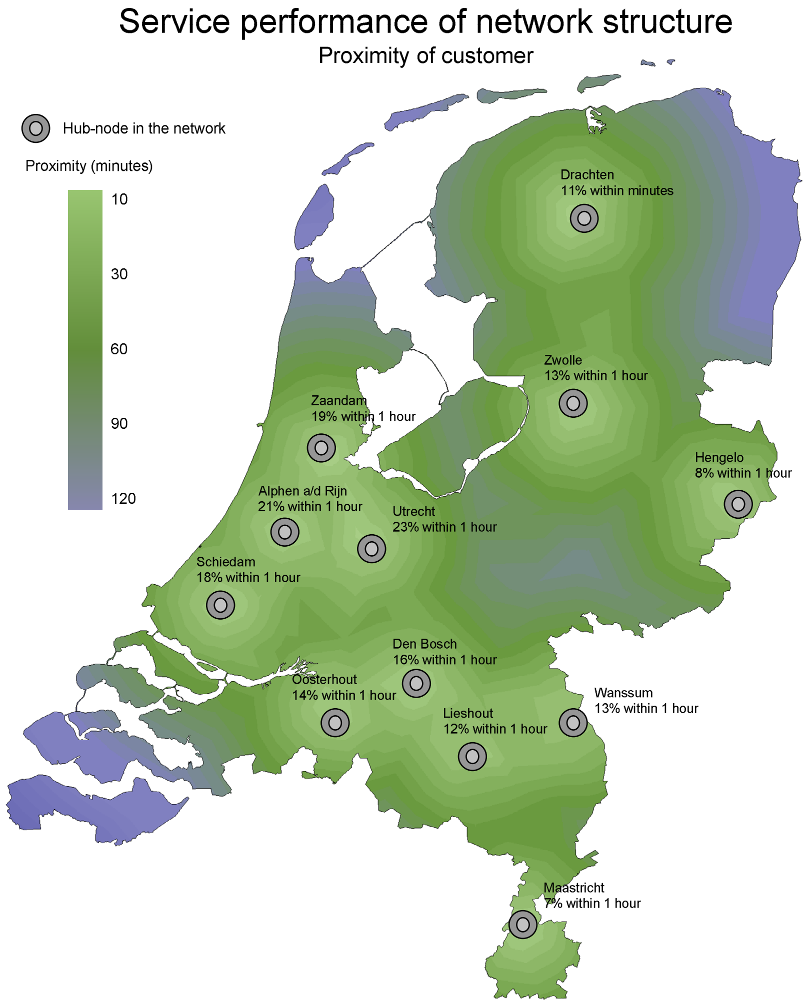

Figure 9-4: Overview of the customer cover performance of the network solution. Based on the shipment times between the hub and the destination.

If our modeling framework is combined with a gain-sharing instrument, optimizing the distribution of the benefits for the consortium, the service provider knows exactly what the optimal offer should be to maximize the cost reduction for the total consortium. The capability to design these complex networks and search for a feasible networks is an important methodological extension. However, the possibility to delineate the development path of these complex networks and, during this development being able to identify those participants that will yield the highest added value, is the primary result of this dissertation that enhances the feasibility of collaborative networks. The innovation on the modeling part was sought in the combination of different techniques, enabling us to design a hub-network, more specifically a collaborative hub-network, based on transaction cost analysis, gaining insight into the feasibility of the development path, and the evaluation of the network solutions.

9.4 Recommendations for further research

In this dissertation, we have paid attention to the limitations of this research project. In this final section, we will discuss the leads for future research that follow from our research activities. First, we will discuss the recommendations for further methodological developments. Our research was aimed at developing a modeling framework and less on the empirical aspects. As we have seen, the incorporation of transaction costs and additional resistances can have a significant impact on the network design. It is therefore of great importance that when the modeling framework is used, these costs and resistance need to be estimated accurately.

In our definition the transaction costs consist of two parts: $\delta^{tc} = \delta^{tcI} + \delta^{tcII}$. The first category is caused by the first round of information problems, excluding the intervention of opportunism, while the second category indicates the consequential costs arising from the strategic exercise of information asymmetry by the informed party. In our case-study we estimated these costs based on the interviews and information provided by the participants and were able to derive founded conclusions using a bandwidth for these costs. It is however, recommended that a stated preference survey or similar instrument is used to systematically list these costs to be used during the network design.

Second, the impact of the distribution of the benefits within the consortium is of great importance. This issue received little attention in this dissertation but should be examined in detail, because this can influence the decision-making process significantly. How well can the effects, (benefits, costs, risks, etc.) be measured and communicated between (potential) partners and then distributed in such a way that all participants agree.

A third recommendation is to apply this modeling framework in other network sectors. For example in the telecommunication sector, were customer switch between different networks and make this decision based on costs, service, but, in addition, on the transaction costs. The accompanying network could be derived using the modeling framework. Another sector could be the energy and utility market. Again, the network design depends on the costs, service and transaction costs.

If we combine our network design framework with a gain-sharing instrument, optimizing the distribution of the benefits of the consortium, the participants or service provider know exactly what the optimal offer should be to maximize the cost reduction for the total consortium or of course, in a commercial setting, maximize their own profit. The capability to design these complex networks and search for feasible network is an important methodological extension valuable for designing collaborative hub networks and could be well used by service providers optimizing their logistics networks.

We only briefly discussed the changing logistics environment and the impact this might have on the way business and logistics is organized. Next to the performance in terms of costs and logistics service we focused on in this dissertation, an additional performance indicator could be incorporated to the design frame work. This should cover the sustainability of the network solutions. This then makes it possible to assess the network performance in terms of fuel consumption, vehicle kilometers, emission, noise, etc. In addition, an extra objective could be implemented (minimizing the external costs). For example, by incorporating the external costs into the integral costs (next to logistics costs and transaction costs).

The basic unit of analysis of transaction cost economics is the transaction laid down in a contract or agreement between two trading parties. Next to the logistics costs and service of the network solution the decision to participate is based on these transaction costs. Game theory is the study of the ways in which strategic interactions among rational players produce outcomes with respect to the preferences (or utilities) of those players, none of which might have been intended by any of them. The process of bargaining and deciding to participate could be addressed by Game Theory in combination with the transaction cost approach.

The study of multi-agent systems focuses on systems in which intelligent agents interact with each other. The agents are considered to be autonomous entities, such as software programs or robots. Their interactions can be either cooperative or selfish. That is, the agents can share a common goal (e.g. an ant colony), or they can pursue their own interests (as in the free market economy. This technique could prove to be useful in addition to the network design framework.

In Chapter 7 we discussed the equilibrium properties of our design problem. We illustrated that the costs are dependent of the use of the network and the use of the network depends on the costs. This 'reciprocal influence' can be approached as a MPEC problem, making it an equilibrium problem.

Our final recommendation is on the field of optimization and solving these complex network design problems. Research should go into a better understanding of advancing hub network design optimization methods for logistics costs in realistic networks and reducing the CPU-time for solving these complex problems.

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APPENDICES

COLLABORATIVE LOGISTICS AND TRANSPORTATION NETWORKS

A MODELING APPROACH TO HUB NETWORK DESIGN

Appendix A: Initiatives in collaboration

Table I: Overview of collaboration initiatives with their objective and scope

Examples of *Operational*, *Coordination* and *Network collaborations*

Collaboration	Description	Objective	Type	Source
Factory Gate Pricing $\bullet / A / Sc / \bullet / costs, II$	This is an initiative with a focus on transport optimization. The manufacturer delivers the products ex.works and the retailer picks up the products. The retailers thus govern these inbound flows. Especially when shipment size are relatively small the benefits can be considerable	costs minimization by transport optimization and vehicle routing optimization	II	Wilschut 2004
Citybox $\bullet / A / Sc / R / reliability, II$	Due to the problems in city distribution (time windows, vehicle restrictions, congestion) a small sized container is introduced that can be easily transshipped from a 6-box vehicles, used for the line haul and a 2-box vehicle used for distribution in the city.	reliability increase by transport optimization and consolidation of flows.	II	Stadsbox Consortium 2005, Groothedde and Rustenburg 2003c.
Foodnet $\bullet / \bullet / Sc / R / asset, I$	This is an initiative with a focus on transport optimization and asset efficiencies. Several logistics service providers (Bakker Logistiek Groep, Kees Becker, Christian Salvesen, Tibbet&Britten, Maxser, ACR logistics, Portena Logistiek, C. van Heezik, van Uden Food Express, and Zuidema Logistiek). By sharing information LTL-loads are exchanged to optimize load planning.	asset efficiency by information exchange, vehicle routing and load planning.	I	TNO *et al.* 2003
Zoetwaren Distributie $\bullet / \bullet / Sc / R / asset, I$	This is a collaboration that consists of several manufacturers of confectionary products in the Netherlands that optimize the replenishment of the retail warehouses by cross docking and consolidation of flows.	Asset efficiency by consolidation, cross docking and vehicle routing	I	Vos et al. 2002, 2003
Fresh Consolidation Center $\bullet / \bullet / Sc / R / costs, I$	In this collaboration the products of the farmers (greenhouse) . The former auction organization functions as a cross docking location. After cross docking the flows are shipped to the retail warehouses.	Inventory optimization, vehicle routing, scheduling skilled labor	I	ATO-DLO et al. 2002
Vos Logistics & Ahrend $\bullet / A / Sc / \bullet / costs, II$	Collaboration between LSP and wholesaler in office supplies, using standardized loading units with office furniture and supplies	Inventory optimization, vehicle routing, scheduling skilled labor.	II	TNO *et al.* 2003
Fast Moving Cosmetics $\bullet / A / Sc / \bullet / costs, II$	Schwarzkopf en Henkel cosmetics both produce fast moving consumer cosmetics (85% of production in Germany). In this collaboration both manufacturers consolidate their inbound flows.	Transport cost minimization, consolidation	II	Bahrami 2002
Confectionary Germany $\bullet / A / Sc / \bullet / costs, II$	This is a collaboration that consists of several manufacturers of confectionary products in the Netherlands that optimize the replenishment of the retail warehouses by cross docking and consolidation of flows.	asset efficiency by information exchange, vehicle routing and load planning.	II	Dulleart *et al.* 2004, Schroeter 2004.
Dairy Product US $\bullet / A / Sc / \bullet / costs, II$	Collaboration between different service providers and manufacturers with the objective to consolidate the flows (on the line-and backhaul). Land O'Lakes is using the Web to share supply trucks to better coordinate deliveries.	asset efficiency by information exchange, vehicle routing and load planning.	II	Buss 2003
Distribouw $\bullet / \bullet / Sc / R / asset, I$	Initiative of four carriers, exchanging information and transport orders (building materials). Broeders Transport bv , Kluitmans Transporten, Transportbedrijf Verheul, Internationaal Transportbedrijf Vink	costs minimization by transport optimization and vehicle routing optimization	I	Distribouw 2004
Toyota Manufacturing $S / A / Sc / \bullet / service, III$	Toyota, a leader in production efficiency, is teaming with small American suppliers in an effort to enhance these firms' productivity. Toyota is cultivating these relationships and teaching them their production know-how.	Customer service, Asset efficiency increased productivity	**III**	Gundlach and Murphy 1993. Inaba 2004.

Appendix B: Cooling Schedules

Various cooling schedules can be used with a *Simulated Annealing* optimization. τ_i is the temperature for cycle i, where i increases from 0 to N. The initial and final temperatures, τ_0 and τ_f respectively, are determined by the user, as is N.

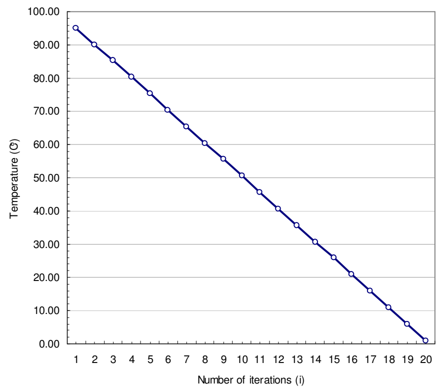

Figure I: Cooling schedule 1

$$\tau_i = \tau_0 - i \bullet (\frac{\tau_0 - \tau_f}{N})$$

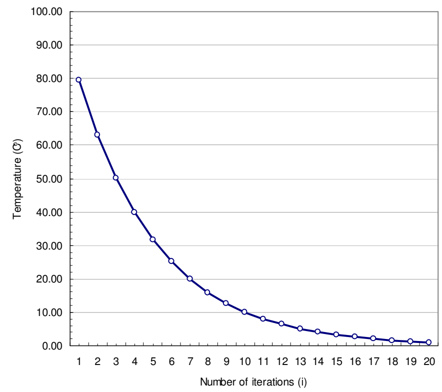

Figure II: Cooling schedule 2

$$\tau_i = \tau_0 \bullet (\frac{\tau_f}{\tau_0})^{i/N}$$

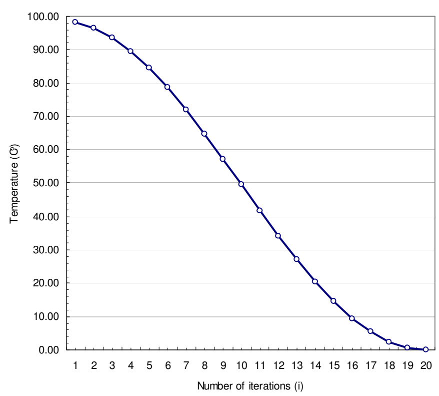

Figure III: Cooling schedule 3

$$\tau_i = \frac{1}{2}\left(\tau_0 - \tau_f\right) \bullet (1 + \cos(\frac{i\pi}{N})) + \tau_f$$

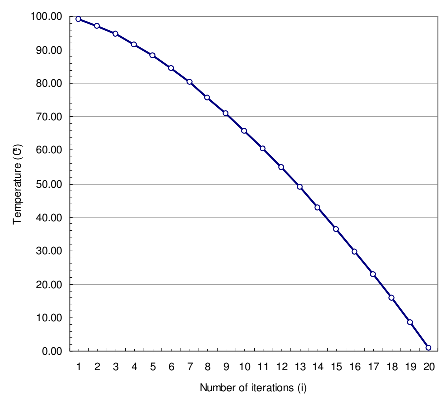

Figure IV: Cooling schedule 4

$$\tau_i = \tau_0 - i^{\ln(\tau_0 - \tau_f)/\ln(N)}$$

Appendix C: Solution procedure SA

The term annealing in physics describes the process in which a solid is heated to a high temperature τ_0 , where the atoms randomly arrange themselves in liquid phase, and then it is cooled gradually according to a cooling schedule $\{\tau_0 > \tau_1 > \tau_2 > \tau_3 ... \tau_f\}$, where T_f is the freezing point. At τ_f the solid is said to be in its lowest energy state (ground state). The amount of time spent at each temperature level during the annealing process must be long to allow the system to reach thermal equilibrium (steady state). If cooling down is done quickly (rapid quenching), undesirable random fluctuations of the atoms get frozen into the material, thereby making the attainment of the ground state impossible. Metropolis *et al.* (1953) developed a simple Monte Carlo approach to simulate the behavior of a collection of atoms in achieving thermal equilibrium at a given temperature level. The idea is to start from a current configuration of the atoms and apply a small randomly generated perturbation. If this results in a lower energy state, the process is repeated using a new state. If, however, the result of the perturbation is a higher energy state, then the new state is accepted with a certain probability.

Based on these results and on its versatility, flexibility and robustness, SA was used as the search procedure for our design problem. Kirkpatrick *et al.* (1983) were the first to apply the idea of annealing to combinatorial optimization problems. They mentioned the analogy between statistical mechanics and combinatorial optimization problems and applied the simulated annealing approach to the solution of a circuit board layout and wiring problem, and to the traveling salesman problem. They proposed a method of using a *Metropolis Monte Carlo*[35] simulation to find the lowest energy (most stable) orientation of a system. The temperature of the glass is slowly lowered so that at each temperature the atoms can move enough to begin adopting the most stable orientation. They concluded that good quality solutions to both of these problems are attainable with annealing schedules for which the amount of computational effort scales as *n*, or as a small power of *n*. Encouraged by these results, they hypothesized the fruitfulness of a wide application of this heuristic technique to other combinatorial optimization problems. Golden and Skiscim (1984) investigated the application of simulated annealing to traveling salesman problems and to *p*-median network allocation problems. Wilhelm and Ward (1987) presented an application of simulated annealing for solving quadratic assignment problems. Since then, the method has been referred to as simulated annealing. In the analogy, the different states of the substance correspond to different feasible solutions to the combinatorial optimization problem, and the energy of the system corresponds to the function to be minimized. Simulated annealing offers a strategy that is similar to iterative improvement techniques with one major advantage: iterative improvement techniques only allow moves that decrease the cost function (downhill moves), whereas simulated annealing allows moves that increase the cost function (uphill moves) in a controlled manner (cooling schedule). This idea makes it possible to leave local minima and potentially

[35] In a simple Monte Carlo simulation, all random moves are accepted such that a different region of search space is sampled at each step. In 1953, Metropolis *et al.* proposed a new sampling procedure which incorporates a temperature of the system. This is done so that the *Boltzmann* average of a property of the system can be easily calculated (see footnote 38). This modified Monte Carlo method is known as a Metropolis Monte Carlo simulation and was first presented in Metropolis *et al*. (1953).

fall into a more promising downhill path. The notion of a temperature parameter is to control the acceptance of uphill moves. At the beginning (high temperatures), most uphill moves are accepted to permit an aggressive search of the configuration space. As the search proceeds (temperature drops) the solution should be close to a near-optimal solution and fewer uphill moves are allowed.

Schedule of standard Simulated Annealing algorithm

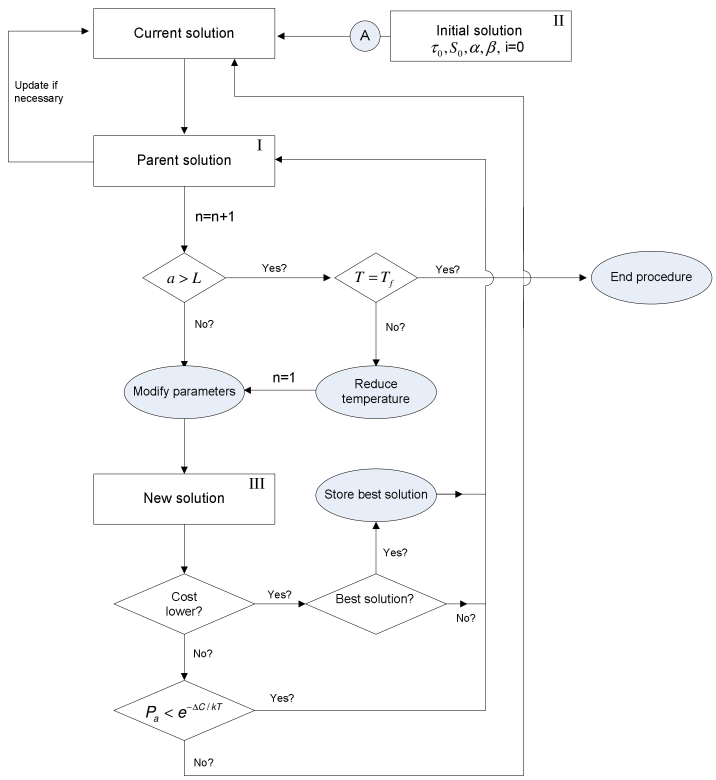

Figure V: : Schedule of the standard simulated annealing algorithm.

I) The *Parent solution* is the solution that is under *construction* and improved upon using different strategies.
II) The *Initial solution* can be generated randomly or using a feasible network.
III) During this step the *New solution* is generated.

A *Simulated Annealing* optimization starts with a Metropolis Monte Carlo simulation at high temperature. This means that a relatively large percentage of the random steps that result in an increase in the energy will be accepted. After a sufficient number of Monte Carlo steps, or attempts, the temperature is decreased. The Metropolis Monte Carlo simulation is then continued. This process is repeated until the final temperature is reached.[36] In Figure V the standard SA procedure is illustrated. A SA optimization starts with an initial solution to the problem (S_0), which is also the *Best solution* so far, and the temperature set at the initial, high temperature (τ_0). This solution becomes the *Current solution* and the *Parent solution*. The number of Monte Carlo (i) attempts is set to 0.

Then i is incremented by 1 and is tested to see if it has reached the maximum number of attempts at this temperature (L). If so, the current temperature is checked (τ). If it is equal to the final temperature, τ_f the simulation is finished and both the *Final solution* and the *Best solution* are found during the simulation. If the current temperature is above the final temperature ($\tau > \tau_f$), it is reduced using a cooling schedule[37]. The number of Monte Carlo attempts i is reset to 1. If the number of attempts at this temperature has not been reached ($i < L$), or the temperature has been decreased, the *Parent solution* is modified to generate a *New solution*. This constitutes the Monte Carlo step. If the costs of the *New solution* is lower than that of the *Parent*, it is checked to see if it is the *Best solution* found to date. If it is, it is stored separately. Whether or not it is the best, it becomes the new *Parent solution* for the next Monte Carlo step. Whenever the *Parent solution* is updated, so is the *Current solution*. If the costs of the *New solution* are higher than the *Parent's* by an amount ΔC, the Boltzmann probability ($e^{-\Delta C/\kappa\tau}$ where κ is Boltzmann's constant[38] and τ is the current temperature) is calculated. If this probability is greater than a random number (Prob^{ac}) between 0 and 1, this *New solution* is accepted and becomes the *Parent solution* for the next iteration, and the *Current solution*. Conversely, if the Boltzmann probability is less than Prob^{ac}, the *New solution* is rejected and the *Current/Parent solution* stays the same and is used in the next iteration. This constant is not necessarily required when applying the *Metropolis* algorithm to combinatorial problems. Consider the value of the exponent $e^{-\Delta C/\kappa\tau}$ under different conditions. The probability of moving from a high-energy state to a lower-energy state is very high. However, there is also a non-zero probability of accepting a transition into a high-energy state, with small energy jumps much more likely than big ones. The higher the temperature, the more likely such energy jumps will occur. A physical system, as it cools, seeks to go to a minimum-energy state. For any discrete set of particles, minimizing the total energy is a combinatorial optimization problem. Through random transitions generated according to the above probability distribution, we can simulate the physics to solve arbitrary combinatorial optimization problems. There are several cooling schedules available in literature (Collins *et al.* 1988; Luke 2005). In practice, two different cooling schedules are used; a linear cooling schedule ($\tau = \tau + \alpha\tau$) and a proportional cooling schedule ($\tau = \alpha\tau$) where $0 < \alpha < 1$.

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[36] In physical systems the term *state* is often used, when used in optimization application it refers to a *feasible solution*. Other analogies between physics and simulated annealing are *energy* versus *cost*, *ground state* versus *optimal solution*, *rapid quenching* versus *local search* and *careful annealing* versus *simulated annealing*.

[37] See for an overview of cooling schedules Appendix B: with 4 different schedules.

[38] *Boltzmann's constant*, symbolized κ or κ_b, defines the relation between absolute temperature and the kinetic energy contained in each molecule of an ideal gas. The value of Boltzmann's constant is approximately 1.3807 x 10-23 joules per Kelvin. In general, the energy in a gas molecule is directly proportional to the absolute temperature. As the temperature increases, the kinetic energy per molecule increases. As a gas is heated, its molecules move more rapidly. This produces increased pressure if the gas is confined in a space of constant volume, or increased volume if the pressure remains constant.

Appendix D: Performance of the solution procedure

Simulated Annealing can deal with highly non-linear models, chaotic and noisy data and many constraints and has proven to be a robust and general technique (Eglese 1990; Abdinnour-Helm 1998). The main advantage over other local search methods are its flexibility and its ability to approach global optimality. Simulated Annealing methods can be *tuned* fairly easily. For any reasonably difficult non-linear or stochastic system, a given optimization algorithm can be tuned to enhance its performance and since it takes time and effort to become familiar with a given code, the ability to tune a given algorithm for us in more than one problem should be considered an important feature of an algorithm. A disadvantage is the fact that Simulated Annealing is a meta-heuristic and therefore a lot of choices are required to turn it into an actual algorithm.

Any efficient optimization algorithm must use two techniques to find a global optimum: exploration to investigate new and unknown areas in the search space, and exploitation to make use of the knowledge found at points previously visited to help find better points. These two requirements are contradictory, and a good search algorithm must find a trade-off between these two factors.

The SA heuristic was tested using two types of data sets: the CAB data set and the AP data set. The former is a real world data set (O'Kelly 1987), which has been consistently used in the literature. The data are based on airline passenger flow between 25 US cities in 1970, as evaluated by the Aeronautics Board (the CAB data set). A second data set that is used in the literature is the AP data set. This set consists of 200 nodes, which represent postcode district, along with their coordinates, flow volumes (mail flow), as well as the *collection*, *transfer*, and *distribution costs*.[39]

In addition to the SA-algorithm we included five other solution methodologies in the table listing the results of the small-sized CAB problem. Campbell (1995) developed two heuristics to solve the p-hub problem. By using a Greedy exchange heuristic, the multiple assignment problem is solved first. The first heuristic, MAXFLOW, assigns a node to a hub through which it has its maximum flow. The second heuristic, ALLFLOW, allocates a node to a hub in order to minimize the total transportation cost. Skorin-Kapov and Skorin-Kapov (1994) proposed a tabu search (TS in Table II and Table III) obtain very good results on many of test results. Ernst and Krisnamoorthy (1996) presented a SA heuristic (SA1) and a Branch and Bound algorithm (B&B) to solve the p-hub problem.

Table II and Table III report the results of SA, SA1, MAXFLOW, ALLFLOW, TS, and B&B on the CAB data set for $n=10$ and $n=25$. The first half of each table reports the actual values of the transportation costs for al the heuristics at each level of α_s, and for p values equal to 2, 3 and 4. The last two columns indicate the percentage difference between the cost for each heuristic and the minimum cost for the solution methodologies. The term NA under the ALLFLOW column indicates that there is no available information. The TS heuristic performed best, because the transportation cost for all the problems (100%)

[39] The CAB data set and the AP data set is available at the OR library, Beasly (2005). OR-Library is a collection of test data sets for a variety of Operations Research (OR) problems and was originally described in Beasley (1990).

considered was the minimum.[40] The SA algorithm came in second with approximately 70% of the problems achieving the minimum cost value. However the SA1 heuristic performed as well as the TS heuristic yielding 100% minimum costs on the problems considered in both comparisons. The average %difference of SA was very low (approximately 0.2), and so was the standard deviation (approximately 0.4) indicating a very low variation.

Table II: Transportation cost comparison for *n=10* (CAP data set)
actual values and percentage difference from minimum cost

		Actual values						%Difference	
α_s	*p*	SA[I)]	SA1[II)]	MAXFLOW	ALLFLOW	TS	B&B	SA	SA[I)]
1	2	835.81	835.81	854.31	849.26	835.81	861.05	0.00%	0.00%
	3	776.68	776.68	808.91	784.59	776.78	817.84	0.00%	0.00%
	4	737.47	736.26	911.45	782.18	736.26	769.83	0.16%	0.00%
0.8	2	790.94	790.94	808.03	790.94	790.94	805.26	0.00%	0.00%
	3	716.98	716.98	743.66	717.48	716.98	751.18	0.00%	0.00%
	4	661.41	661.41	718.3	692.36	661.41	685.49	0.00%	0.00%
0.6	2	723.63	723.63	761.75	732.63	732.63	726.16	0.00%	0.00%
	3	643.89	643.89	650.38	643.89	643.89	660.89	0.00%	0.00%
	4	581.77	577.83	601.37	577.83	577.83	592.97	0.68%	0.00%
0.4	2	674.31	674.31	674.31	674.31	674.31	674.51	0.00%	0.00%
	3	572.24	567.91	583.27	567.91	567.91	570.69	0.76%	0.00%
	4	494.95	493.79	510.38	493.79	493.79	502.73	0.23%	0.00%

[I)] The implemented Simulated Annealing algorithm based on Abdinnour-Helm (2001)
[II)] Simulated Annealing algorithm Ernst and Krishnamoorthy (1996)

Table III: Transportation cost comparison for *n=25* (CAP data set)
actual values and percentage difference from minimum cost

		Actual values						%Difference	
α_s	*p*	SA[I)]	SA1[II)]	MAXFLOW	ALLFLOW	TS	B&B	SA	SA[I)]
1	2	1359.19	1359.19	1368.96	NA	1359.19	1412.20	0.00%	0.00%
	3	1261.08	1256.63	1322.17	NA	1256.63	1303.13	0.35%	0.00%
	4	1216.68	1211.23	1272.69	NA	1211.23	1270.82	0.45%	0.00%
0.8	2	1294.08	1294.08	1294.08	1294.08	1294.08	1339.76	0.00%	0.00%
	3	1158.83	1158.83	1176.52	NA	1158.83	1205.18	0.00%	0.00%
	4	1087.66	1087.66	1090.9	NA	1087.66	1137.69	0.00%	0.00%
0.6	2	1201.21	1201.21	1201.21	1201.21	1201.21	1225.71	0.00%	0.00%
	3	1033.56	1033.56	1039.64	1039.64	1033.56	1068.49	0.00%	0.00%
	4	939.21	939.21	939.21	939.21	939.21	967.76	0.00%	0.00%
0.4	2	1101.63	1101.63	1108.33	1101.63	1101.63	1105.82	0.00%	0.00%
	3	903.52	901.70	903.49	903.49	901.70	923.97	0.20%	0.00%
	4	787.51	787.51	794.89	794.49	787.51	802.32	0.00%	0.00%

[I)] The implemented Simulated Annealing algorithm based on Abdinnour-Helm (2001)
[II)] Simulated Annealing algorithm Ernst and Krishnamoorthy (1996)

In Table IVthe results of the large-sized data set is presented for the two SA-heuristics SA and SA1. On this larger data set SA performs well. For the problems up to $n = 50$ the heuristic is

[40] Skorin-Kapov *et al.* (1996), proved that all the TS heuristic solutions turned out to be equal to the optimal solutions.

able to reach the optimal value. For the larger problems no exact solution is available. However, we have included the results to show how the heuristic algorithm produces results for much larger problems in a reasonable amount of computing time. As expected, the running times increase significantly as the number of nodes and hubs are increased.

Table IV: Transportation cost comparison a large sized problem (AP data set)
actual values and percentage difference from lowest value and average CPU

			Actual values		%Difference		Average CPU	
α_s	*n*	*p*	SA[I)]	SA1[II)]	SA[I)]	SA1[II)]	CPU	CPU1[III)]
0.75	40	2	177,822.31	177,471.67	0.20%	0.00%	3.23	4.34
	40	3	159,131.21	158,830.54	0.19%	0.00%	5.12	6.92
	40	4	143,900.21	143,968.88	0.00%	0.05%	8.01	9.07
0.75	50	2	178,278.32	178,484.29	0.00%	0.12%	7.23	8.68
	50	3	160,019.22	158,569.93	0.91%	0.00%	9.87	12.02
	50	4	144,168.21	143,378.05	0.55%	0.00%	14.12	17.22
0.75	100	5	138,221.34	136,929.44	0.94%	0.00%	65.67	80.55
	100	10	109,512.12	106,469.57	2.86%	0.00%	154.78	161.86
	100	20	83,112.23	80,682.71	3.01%	0.00%	321.78	279.79
0.75	200	5	143,122.76	140,409.41	1.93%	0.00%	278.98	399.73
	200	10	117,031.73	111,088.33	5.35%	0.00%	598.08	776.58
	200	20	88,231.92	85,560.39	3.12%	0.00%	1324.98	1555.90

[I)] The implemented Simulated Annealing algorithm based on Abdinnour-Helm (2001)

[II)] Simulated Annealing algorithm Ernst and Krishnamoorthy (1996)

[III)] Comparison on time can not be made, since the heuristics were written in different programming languages and were run on different types of machines

Appendix E: Dataset characteristics

In Table V an overview of the data set is presented with in total 26,321,000 million pallets distributed over 26 categories based on the provided and estimated information Next to the annual pallet flows, the numbers of production locations where these flows originate are indicated. In the fourth column the average shipment size in pallets is indicated. On average 5.7 pallets are shipped, with the large shipments occurring in beer and soft-drinks. In the fifth column the average delivery frequency in shipments per week to the customers is indicated (between the production location and the retail warehouse).

Table V: Characteristics of the origin and destination matrix of the available dataset
Dataset contains 203 production locations and 250 retail warehouses

Characteristics of the dataset

Product category	Pallets in dataset	Production locations	Average shipment	Frequency	FTL	LTL
Coffee/Tea	655,000	7	4.8	4.3	86.7%	13.3%
Sugar/Sweeteners	993,000	4	4.0	4.3	62.5%	37.5%
Bakery products	530,000	5	8.6	10.0	34.8%	65.2%
Breakfast/Cereals	196,000	3	6.3	4.2	36.2%	63.8%
Baking products/dessert	123,000	3	8.8	3.5	44.0%	56.0%
Soups/Aroma	845,000	4	8.2	8.6	37.8%	62.2%
Condiments/Seasoning	746,000	5	1.1	1.2	60.3%	39.7%
Dietary foods/Reform	377,000	5	1.7	4.3	39.6%	60.4%
Baby foods	431,000	4	7.3	7.5	43.2%	56.8%
Bread fillings&toppings	289,000	12	1.6	6.4	55.2%	44.8%
Biscuits, cookies	762,000	4	1.6	5.3	78.5%	21.5%
Confectionery/sweets	1,098,000	17	2.9	3.2	48.2%	51.8%
Snacks, toast, chips	591,000	10	7.1	6.0	69.1%	30.9%
Frozen foods	1,410,000	7	1.5	4.2	84.2%	15.8%
Beer	3,318,000	13	18.6	8.4	73.1%	26.9%
Wine/Spirit	154,000	1	8.5	7.8	84.4%	15.6%
Non-alcohol, soft drinks	4,902,000	9	17.4	5.5	84.6%	15.4%
Dairy products (non-perishable)	2,582,000	18	6.6	7.6	36.0%	64.0%
Dairy products (perishable)	1,308,000	20	7.3	6.5	70.8%	29.2%
Vegetables, Fruits	51,000	1	6.1	7.0	60.9%	39.1%
Potato	622,000	3	6.5	4.2	86.4%	13.6%
Vegetables, Fruits (non-perishable)	102,000	2	8.2	7.5	58.1%	41.9%
Petfood	165,000	2	8.3	5.2	55.1%	44.9%
Tabacco	157,000	2	2.4	3.1	50.6%	49.4%
Personal, body care	702,000	11	8.3	5.5	67.6%	32.4%
Sanitary towels/napkins	577,000	5	8.4	7.6	85.3%	14.7%
Sanitary tissues	531,000	3	6.5	5.6	68.0%	32.0%
Tissues and paperware	381,000	3	12.8	5.2	60.3%	39.7%
Cleaning product	1,000,000	8	7.4	4.3	75.3%	24.7%
Detergents/cleaning	191,000	3	7.3	5.2	49.4%	50.6%
Office supplies	12,000	1	2.4	1.2	67.9%	32.1%
Alcoholic drinks	251,000	1	8.9	9.6	58.9%	41.1%
Apparel/shoes	85,000	1	8.3	2.1	67.7%	32.3%
Consumer products	184,000	6	7.8	3.2	56.4%	43.6%
Total	26,321,000	203	5.7[1)]	5.4	62%	38%

The average delivery frequency in this data set is 5.4 shipments per week. The last two columns indicate the percentage of the shipments between the manufacturer and the retailer that is sent in Full-Truck-Loads (FTL), or Less-then-Truck-Loads (LTL) . In the total dataset 62% of all shipments are sent in FTLs, 38% in LTLs.

The sales per week in pallets is on average 512,000 pallets per week over all 26 product categories with a peak of +16.8% above average in week 31, and a minimum of -18% below average in week 8. This indicates that when designing a hub network that needs to yield a high utilization of the assets these sales patterns are extremely important and have to be taken into account. The focus group, which provided the information that was used to conduct a detailed analysis of the network design methodology, consisted of nine key manufacturers in the Netherlands, two logistics service providers and the inland shipping carrier. They provided detailed information on the orders and product flows between the manufacturing locations (20) and retail warehouses of four of the largest retailers in food (Albert Heijn, Schuitema, Aldi, and Laurus), wholesalers and additional customers, adding up to 100 customer locations. In total this detailed data set included 6,310,000 million pallets per year. The average sales in pallets per week of the focus group is on 119,000 with a peak in week 32 of 25% above average and -25% below average in week 8.

Appendix F: The Distrivaart project

In the figure below a dedicated pallet barge is illustrated. This barge, named the Riverhopper was built by a barge line operator in 2002 and tested throughout 2003. This type of vessel, with the dimensions 63x7.2 meters and a draught of 2.75 meters, is a relatively small inland barge and can be used on almost all inland waterways throughout Europe

Figure VI: Artist's impression of a dedicated pallet barge, called the Riverhopper.

Figure VII: Artist's impression of the loading and unloading of pallets at the hub.

The capacity in pallets of this specific barge is 550 pallets and it is equipped with a fully automatic onboard warehouse positioning system, making it possible to shuffle the pallets during shipment, thus minimizing the transshipment time at the hub. The first pallet ship to see service was named the River Hopper and carried pallets between various brewers and distribution centers. During this test phase, pallets were still moved around the ship with a forklift truck. An important variable in the design of any inland shipping network is the transshipment technique used, as this can affect both the speed and cost of transshipment.

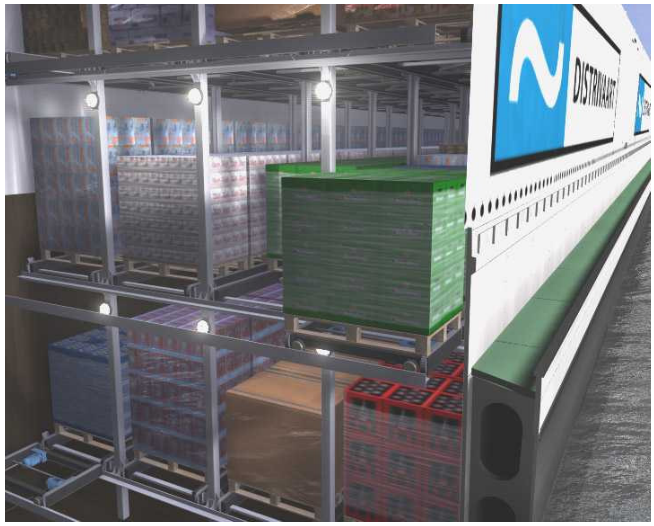


Figure VIII: Interior of the pallet barge with the pallet racks and the pallet-handling and positioning system.

Faster transshipment frees up shipment time, which allows more journeys, and therefore more pallet kilometers, to be made each year with an attendant reduction in cost per pallet. In the figure above an artist's impression is provided of the pallet-handling equipment and positioning system. For a comprehensive overview of the different techniques that were evaluated we refer to Bruin *et al.* (2003).

Appendix G: Overview of the cost components

Based on the information which was provided by three carriers during the Distrivaart project a comparison was made between the calculated road tariffs for shipping pallets and the rate of the three carriers. In Figure IX the comparison between the the realized rates (of the three carriers) and the calculated rates are illustrated. The rates (per shipment) that were calculated were used during the network design phase.

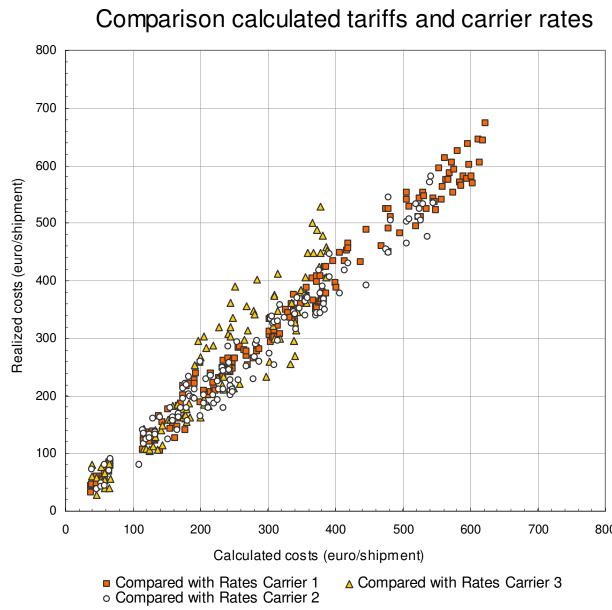


Figure IX: Cost comparison between calculated and realized costs.

In the table below an overview is provided with the parameters related to the direct truck transport and the collection and distribution leg by truck when shipping through the hub network. For example, the initial investment in a truck is set at €135,000 with a depreciation period of 6 years. The hourly labor costs for the driver are estimated at €22. The capacity of the truck (in this example) is 28 pallets. Next we distinguish the Fuel costs, Maintenance costs, and an overhead percentage of 11%. In this example the distance between the origin-destination is 231 kilometer. The type of collaboration we assume is a Type I collaboration, and the contract term is set to 1 year. The order allocation is conducted by the manufacturer and we assume an interest rate of 6.50%.

The total annual flow of pallets is 110,000 and the average stock-keeping units (SKU) per order is 2.90, with an average shipment size of 2,600 pallets. The percentage FTL in this illustrative example is 100%, in other words all shipments on this origin-destination is sent in a Full-Truck-Load. To complete this example we make the assumption on the Average customer lead-time, the Time in inventory, and the value/pallet. The utilization of the barge, a key performance indicator in this network concept, is set to 92%. The total flow inbound and outbound at the hub is 210,000 pallets/year (see Table VII).

Finally, in Table VIII the parameters describing the hub network solution are presented. In this table the investment costs and depreciation periods of the equipment deployed on the interhub transfer is described. For example the investment in the barge (€1,123,000), in equipment (€120,000) and additional investments are presented. For a detailed overview of these costs we refer to Groothedde and Rustenburg (2003a).

Table VI: Overview of the Direct Road transportation parameters

Variable	Units	Input parameters
Investment truck	€	135000
Depreciation period	year	6
Labor costs driver	€/hour	22
Capacity truck	pallets	28
Operational hours	hour/year	2,100
Fuel costs	€/kilometer	0.25
Maintenance	€/kilometer	0.09
Overhead percentage	-	11%
Fixed costs	€/hour	7.56
Fixed time rate	hour	0.35
Variable time rate	hour/pallet	0.04
Distance origin-destination	kilometer	231
Average speed	kilometer/hour	45.40
Time loading/unloading	hour	0.45
Imbalance factor	-	0.11
Average shipment size	pallets/shipment	26

Table VII: Overview of the sequence specific parameters.

Variable	Units	Input parameters
Type of collaboration	-	I
Contract term	year	1.00
Order allocation	-	Manufacturer
Interest rate	%	6.50
Total pallet flow on relation	pallets/year	110,000
Average SKU/order	SKU/order	2.90
Average Shipment size	pallets	26.00
Percentage FTL	-	100.00
Average order size	pallets/order	26.00
Average customer lead-time	hour	19.35
Time in inventory	hour	5.60
Value/pallet	€/pallet	1,450
Time total sequence	hour	12.50
Time inter-hub transfer	hour	6.00
Utilization barge	-	0.92
Utilization hub equipment	-	-
Utilization storage	-	-
Total in/out hubs	pallets/year	210,000
Total positioning moves	moves/year	420,000
Variable costs/move	€/move	0.05
Administration cost per order	€/hour	12.00
Acquisition costs	€/order	0.45
Time/order	hour	0.13
Utilization administration	hour/order	0.87
Number of FTE order administration	FTE	2.00
Order processed annually	order	50,000

Table VIII: Over view of the parameters describing the hub network

Variable	Units	Input parameters
Itinerary regime	-	Semi-continue
Operational hours	hours/year	1,632
Capacity barge	pallets/barge	560
Investment barge	€	1,123,000
Investment Equipment	€	120,000
Investment Positioning	€	0
Depreciation period Barge	year	20
Depreciation period Equipment	year	8
Depreciation period Positioning Eq.	year	7
Building costs ship	€	65,000
Overhead	€/year	35,000
Fuel costs	€/hour	15.00
Maintenance costs	€/hour	3.00
Labor costs Captain	€/year	65,000
Labor costs Other	€/year	40,000
Investment on hub	€	80,000
Investment storage on hub	€	-
Investment administration on hub	€	-
Transshipment capacity	pallets/hour	120
Depreciation period Hub equipment	year	8
Depreciation period Storage	year	-
Harbor fees	€/year	15,000
Labor costs Handling	€/year	34,000
Investment Information system	€	120,000
Depreciation period Information system	year	4
Labor cost Administration	€/year	42,000
Search costs	€	64,000
Bargaining costs	€	52,000
Enforcement costs	€/year	65,000
Hold up offer	€	0
Legal costs	€	0
Value loss	€	0

Appendix H: Physical Network descriptions

Waterways are divided into six classes (CEMT classification), according to the maximum allowed tonnage and the geographical area of competence of waterway managers and this same classification is used in the network we used to calculate the routes, distances and travel-time when inland shipping is used.

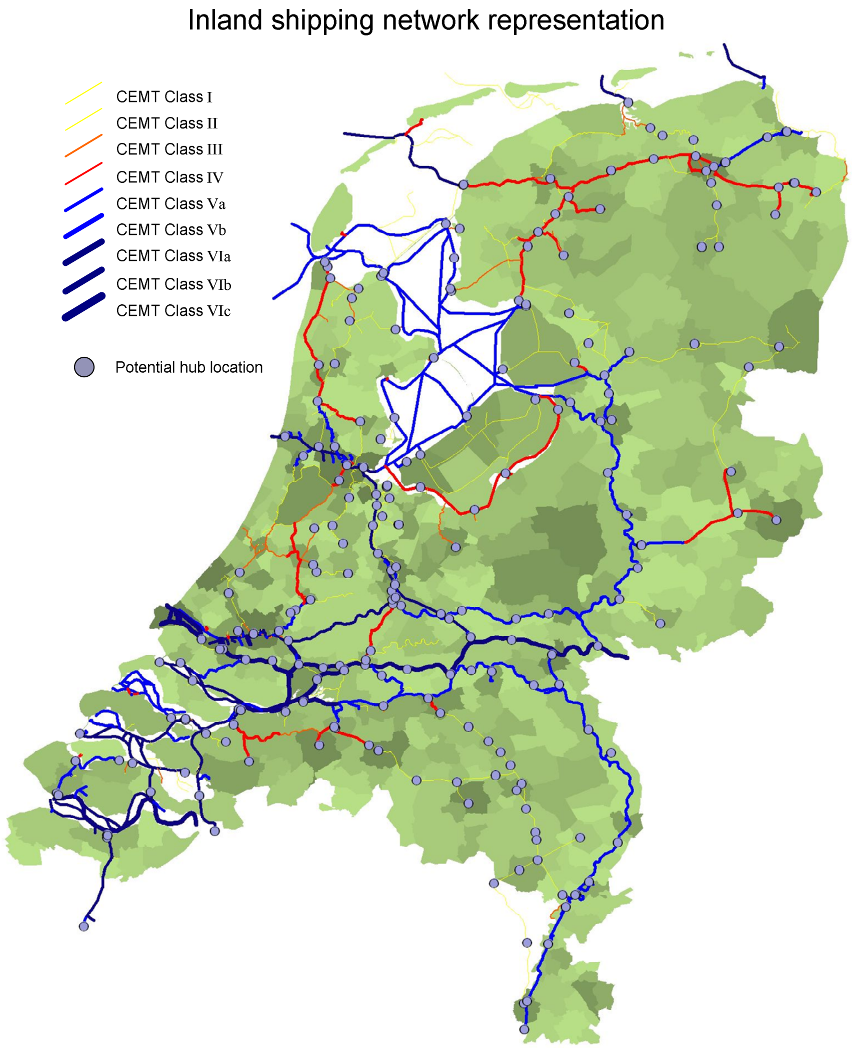


Figure X: Overview of the inland shipping network based on ECDIS network with the CEMT classification used for the inter-hub transfer travel-times and distances, and the potential hub locations.

This classification is based on the historic and current relationship between the size of goods flows on certain corridors and the – in business economic terms – most suitable standard ship sizes and corresponds with the international CEMT classification for ships. Class Va, for instance, corresponds with a standard ship of 110 metres in length, 11.4 metres in width and 2.8 to 4.5 metres in depth, while class VIb corresponds with a standard ship with a length of 140 metres, a width of 15 metres and a depth of 3.9 to 4.5 metres. For a complete overview of the classification see CEMT (2005).

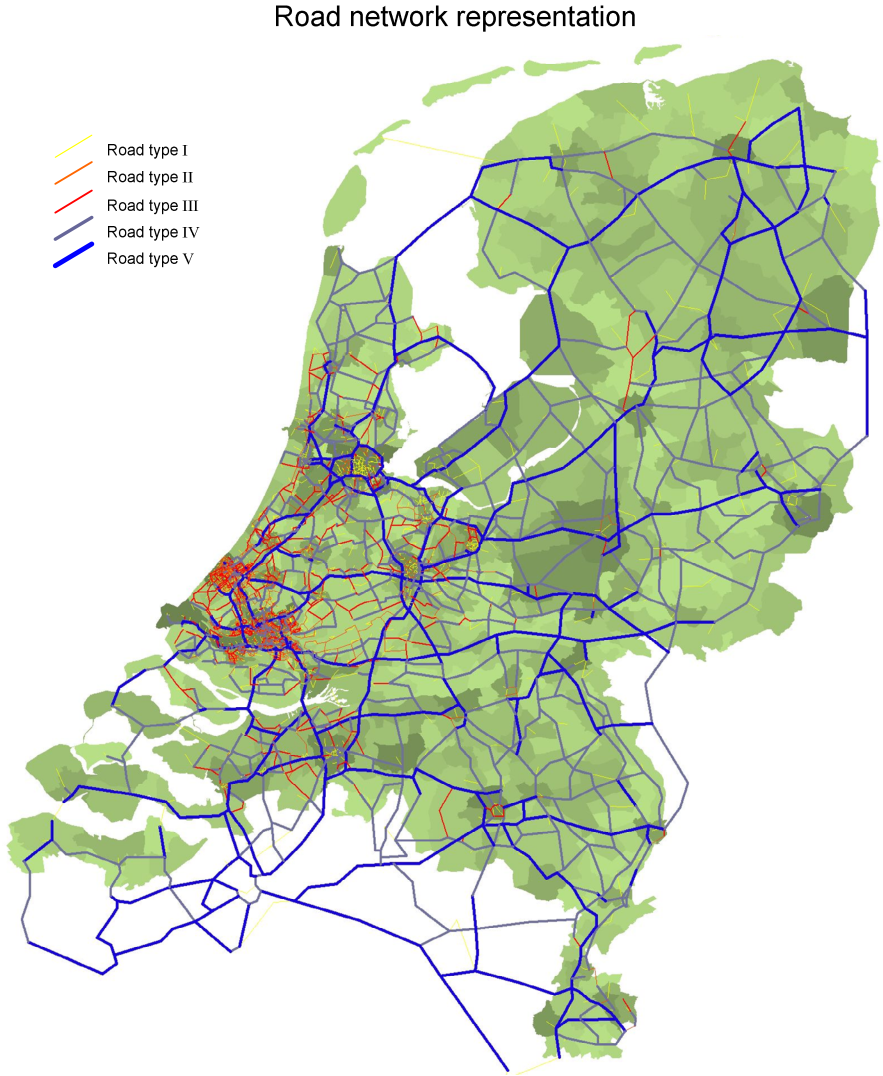


Figure XI: Overview of the road network description used to calculate the travel times and distances between the origin and destinations.

In Figure XI the road network representation that was implemented is presented. Based on the network characteristics (speed, capacity, length, type, etc.) the travel-times, distances and routes are calculated for the collection and distribution leg of a hub network shipment.

Summary

Collaborative Logistics and Transportation Networks, A Modeling Approach to Hub Network Design

Bas Groothedde

The evolution of logistics networks during the last decades can be characterized by a strong rationalization of business processes. Companies have become more aware of the impact that their logistics organization can have on the costs of doing business and on the degree of satisfaction of their customers. This ongoing rationalization has led to a constant search for economies of scale in the supply chain, which has been an important parallel development in line with the changes in globalization and manufacturing.

As more and more production processes become increasingly specialized, an increasing part of the added value is placed outside the company's own facilities, making co-ordination and communication with partners in the supply chain vitally important. A strategy that has become more and more apparent is seeking collaboration with partners in order to achieve the necessary scale and scope to meet these demands. The difficulty when searching for such a partnership in logistics is finding the most appropriate scope, type and form of collaboration.

The term collaboration has taken on several interpretations when used in the context of supply chain management. Based on Schrage (1990) we define collaboration as: "*an affective, voluntary, mutually shared process where two or more actors work together, have a mutual understanding, a common vision, share resources, and achieve common goals. Key dimensions are the cross organizational scope, the commitment to working together, and a common bond or goal*."

By collaboration companies aim to achieve: (1) *Asset or Cost efficiencies*; a potential for cost reduction provides a strong reason to partner, (2) *Customer service*; integrating activities in the supply chain through partnerships can often lead to service improvements for customers in the form of reduced inventory, shorter lead-times, and more timely and accurate information, (3) *Marketing advantage*; a third reason for entering into a partnership is to gain a marketing advantage, and (4) *Profit Stability or growth*; a potential for profit improvement is a strong driver for most partnerships.

Thus far, the design of a logistics network in which the different actors collaborate in order to decrease costs or increase the service level is an issue that has received little attention in the literature. This is in contrast to the amount of attention the organizational issues of partnerships, alliances and supply chain management have received in recent years. Camarinha-Matos and Afsarmanesh (2004) state: "*After an initial phase in which in spite of the considerable investments on collaborative networks, most of the approaches were highly fragmented and case-based, it is now urgent to consolidate and synthesize the existing knowledge, setting a sound basis for the future. One of the main weaknesses in the area is the lack of appropriate theories, consistent paradigms and formal modeling tools*". Instead of solely minimizing the total costs in the logistics

network or minimizing the costs of individual companies, when designing a collaborative network it is necessary to take into account the scope of the collaboration and the type of partnership. The main objective of this study is to develop and demonstrate a design and evaluation methodology for logistics and transportation networks in which the participants collaborate based on (1) the integral logistics costs, (2) the service requirements set by the users of the network, (3) the type of collaboration, and (4) the possible economies of scale throughout the logistics network.

A new design methodology is developed for designing collaborative hub networks and incorporated into a comprehensive framework that was tested in an extensive case study. The network design is based on economic objectives such as minimizing the total costs, minimizing the user costs and the preferred levels of service set by participants. The type of network concept we focus on and that is well-suited to accommodate flows of different shippers is the hub network concept in which the user collaborate. This collaborative hub network design problem is a multiple assignment (participants can use more than 1 hub), combined with direct transportation and we introduce a capacity restriction on the hubs and on the inter-hub transfers. In addition, we incorporate transaction costs that influence the decision of the actors to participate in this collaborative network, based on the asset specificity, uncertainty, frequency and performance of the network solution (e.g. costs, lead-time, and reliability).

The design methodology, yielding feasible network solutions and development paths, is new and is a considerable extension on the current hub network design approaches. In addition we make use of existing simulation techniques. We do not extend the current state-of-the-art but we make use of the available methodologies to evaluate the network solutions derived by the network design procedure. Combining these two approaches, however, in an integrative approach can be considered an additional innovation.

Based on case study research the methodology was validated and tested using actual order and cost information. These findings, based on results of the application of the methodology for different types of collaboration, provide useful guidelines for the design of collaborative networks, insights into the influence the development path of a network has on its feasibility, and will make it possible to evaluate these networks using simulation. The methodology enables the decision-maker to assess different network solutions, a crucial step towards actual implementation of these networks.

The hub network concept is referred to as a dedicated pallet barge network in which specially equipped barges are deployed on the inter-hub connections. The collection and distribution is carried out by road transportation. In addition to shipment using these barges, direct road transportation is still used. This idea of transporting pallets using inland shipping is not new and has been explored in many recent initiatives. However, the concept in this specific configuration, first proposed by Vermunt (1999), explicitly explores the possibility of collaboration and the accompanying economies of scale and scope made possible by joining forces.

An in depth analysis of the network solution was carried out using detailed information provided by several key manufacturers of *Fast Moving Consumer Goods* (FMCG). This group consisted of: Heineken, Bavaria, Grolsch, Coca Cola, Interbrew, Kimberly-Clark, Douwe Egberts, Unilever Bestfoods, Lever-Fabergé, Vos Logistics, Van Heezik, and Riverhopper.

The choice between in-house organization, outsourcing, and collaboration is a fundamental decision in the logistics network. Firms are naturally reluctant to transfer responsibility for an operational area as vital as logistics to a third party. Fears about the loss of control, problems in maintaining customers' goodwill and the inability to replace or supplement at short notice a system that fails to perform are reasons given by logistical managers for not seeking collaboration and contracting out. Therefore an answer to the research question: "*under what circumstances will organizations decide to collaborate with third parties?*" is crucial, in order to be able to design a logistics network in which the different actors collaborate. This decision is based on several key aspects of the collaboration that is considered. In modeling this decision we distinguish the following characteristics:

(1) *Scope and Objective of the collaboration;* based on the hierarchy in decision-making the scope of the collaboration is the structure of the network, the alignment, the scheduling or the resource deployment. The objective of the collaboration is either *asset or cost efficiencies*; customer service, marketing advantage, or *profit stability or growth*.

(2) *Type of collaboration*, we distinguish three types of collaboration; *Type I, operational collaboration*, usually focused at cost and asset efficiency; *Type II, coordination collaboration*; and *Type III, network collaboration.*

(3) *Asset specificity*, in any collaboration the asset specificity for the participants is a key determinant. It is therefore necessary, when modeling the choice-behavior, to gain insight in the asset specificity for all actors.

(4) *Uncertainty,* a second important determinant is uncertainty and a key determinant of the height of the transaction costs (and hereby influencing the choice-behavior substantially).

(5) *Frequency*, the third contingency in *Transaction Costs Analysis,* is the frequency of occurrence. This is considered an important attribute, from the point of view that the costs of specialized, expensive, governance structures will be easier to recover for large transactions of a recurring kind.

(6) *Dominance* reflects its potential for influencing the actions and decisions of individuals and firms in the network.

(7) *Transparency,* refers to the trust between the participating actors and the measurability of the costs, benefits, performance, etc..

When developing collaborative networks it has proven to be crucial to incorporate the transaction costs and additional resistances. Already during the network design these costs, based on the type of collaboration, should be taken into account. As the decision to participate is highly influenced by these costs and the impact on the network structure can be far reaching, it is important to be able distinguish between feasible and unfeasible network solutions in an early stage. Whether transaction costs are high or low, the impact of these costs on the structure of the network is extensive. It is therefore imperative to be able to choose a collaboration strategy, deciding on the type of collaboration and given the scope, objective, asset specificity and other characteristics, be able to gain insight in the accompanying transaction costs, and feasible network solutions. It is important to be able to make this assessment, not only because of the implications on ones' own transaction and logistics costs but in a collaborative network the structure of the network and the costs of all individual companies, is influenced by its partners also. To illustrate this we present an example in Figure XII. The two manufacturers, denoted M_2, the logistics service provider (L), and retailer (R) participate in an initiative to minimize the pipeline inventory.

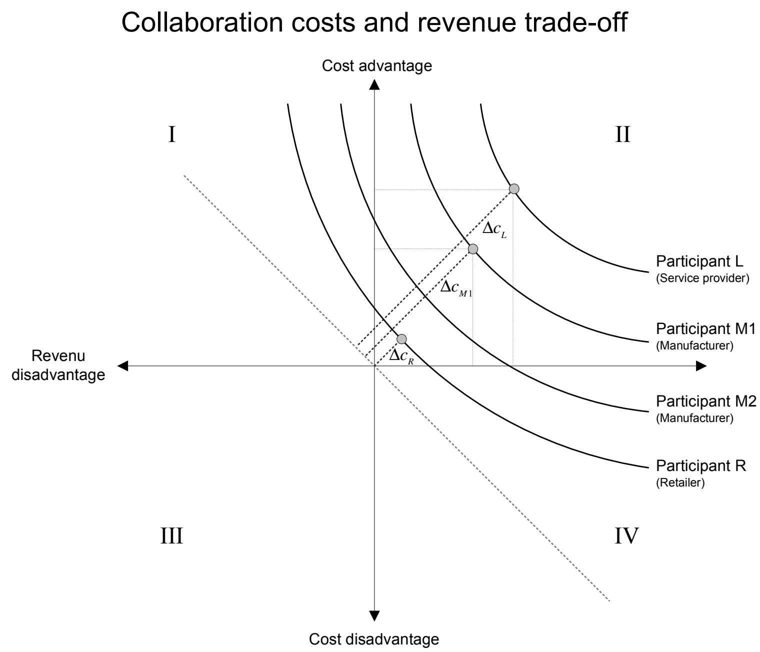


Figure XII: The trade-off between cost and revenues advantages and disadvantages when collaborating.

The logistics service provider (L) governs and initiates the collaboration and we assume the service providers needs to invest heavily in information technology and a dedicated warehouse. The transaction costs of the service provider are $\delta^{tcI} = \left(c^{sc} + c^{bc} + c^{ec}\right)$, in which search costs (c^{sc}), bargaining costs (c^{bc}), and enforcement costs (c^{ec}) are included. As the service provider initiates this collaboration the search costs (c^{sc}) can be become considerable (sales manager, assistant, legal advisor, and operational manager, etc.). Based on the characteristics of the collaboration, in this example a Type II collaboration between two manufacturers, a logistics service provider, and a single retailer, the asset specificity, the transaction costs, and the additional resistance can be calculated for each individual actor. In this example both manufacturers have to invest in information technology and minor changes in their production process. Their transaction costs consist of search costs, bargaining costs and enforcement costs, but as the initiative and governance lays with the service provider these transaction costs are minor in comparison with the service provider. The retailer only makes some search costs, bargaining costs and enforcement costs so there is relatively very little uncertainty associated with participating and given their dominant position there is little resistance to participate to be expected. In Figure XII the trade-off between the disadvantages and advantages is illustrated for these four actors in the network. In our example the service providers has the highest resistance to participate (Δc_i) due to the high asset specificity and uncertainty. The fact that the retailer has a dominant position in this constellation also increases the resistance of the service provider. It is therefore quite logical that the service provider will incurre safeguards. By taking the roles, relations between the actors, and the type of collaboration (with the specific implications this has for the individual participants) into account enables us to estimate the cost and revenue trade-offs per individual actor.

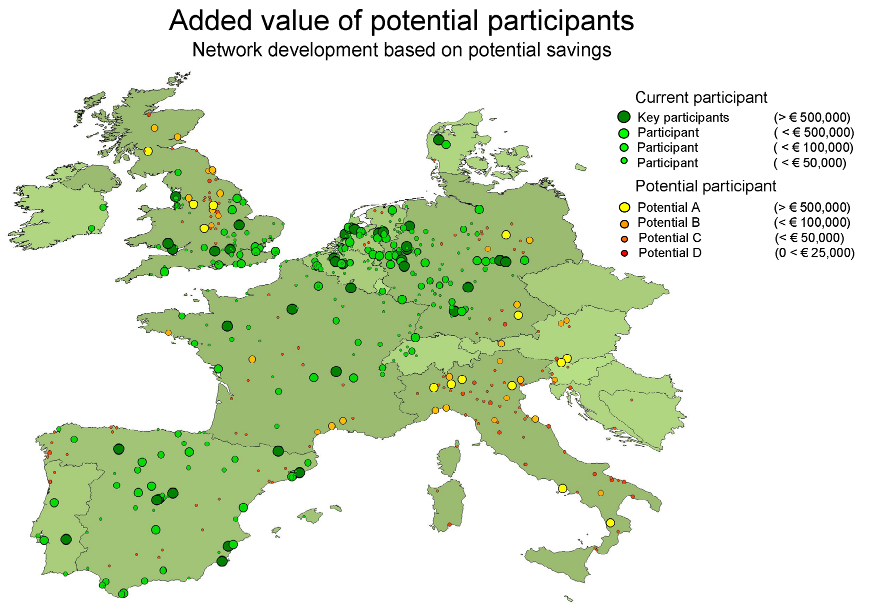


Figure XIII: added value to the network of the current participant and the potential added value of the potential participant.

It is evident that a decision concerning the structure of the logistics network, for example the number of warehouses in the network, influences the inventory policy, and transport planning. To understand these inter-dependencies between the different levels of decision-making in logistics the use of models is essential and this capability to calculate and design these networks is very important. In addition, the combination with evaluative tools is very valuable, especially in collaborative logistics where transparency and measurability can be decisive. The comprehensive design methodology, capable of calculating the logistics costs, the transaction costs, evaluate the network solutions, and delineate the network development could be an important enabler in collaborative networks, but can not be seen separately from other activities in the collaboration building process. For logistics service providers this methodology could help to target potential customers and instead of waiting for an *out-sourcing*-decision of these potential customers, the service provider can actively approach these retailers or manufacturers, offering them a competitive quotation. If our modeling framework is combined with a gain-sharing instrument, optimizing the distribution of the benefits for the consortium, the service provider knows exactly what the optimal offer should be to maximize the cost reduction for the total consortium. The capability to design these complex networks and search for feasible networks is an important methodological extension. However, the possibility to delineate the development path of these complex networks and during this development being able to identify those participants that will yield the highest added value is the primary result of this dissertation, that enhances the feasibility of collaborative networks. When we compare the results of the network design when no transaction costs are incurred (lower-bound variant) the number of participants is relatively high. Introducing transaction costs, changes the network structure and some participants decide not to join this new network because of the changes in structure.

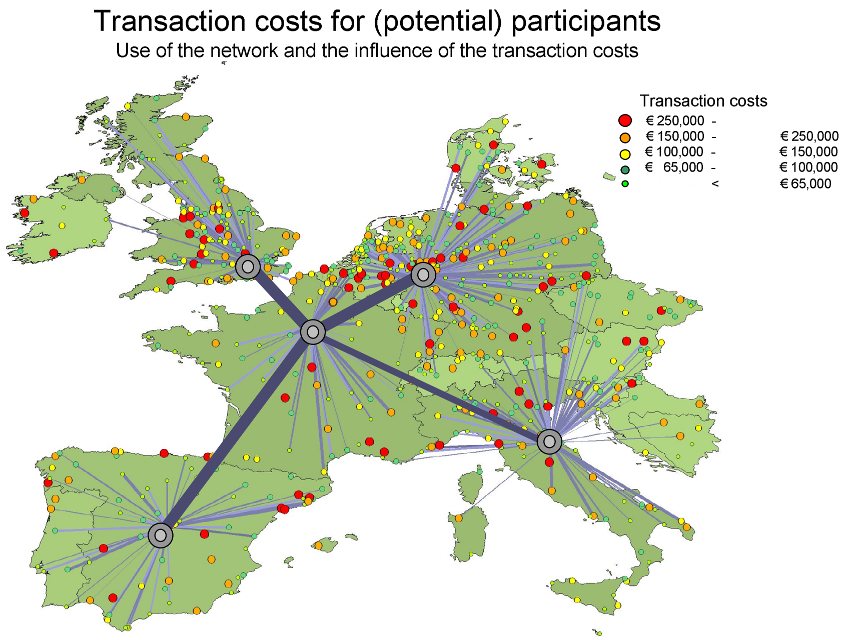


Figure XIV: The individual transaction cost per participant and the use of the network solution.

This group of former participants is mostly affected by the changes in structure, not so much by the transaction costs themselves. But other former participants that decide not to join the collaboration, influence the network structure in such degree that others decide to exit (second order effect). An additional group of former participants decide not to join the new network because of the transaction costs, even though the new network structure is cost efficient in terms of the integral logistics costs (costs per pallet) compared to direct shipment.

The possibility to delineate the development path of these complex networks and during this development being able to identify those participants that will yield the highest added value is the primary result of this dissertation.

Samenvatting

Samenwerking in Logistieke en Transportnetwerken
Een modelmatige aanpak voor het ontwerp van hub netwerken

Bas Groothedde

De evolutie van logistieke netwerken de afgelopen decennia wordt gekenmerkt door een sterke rationalisatie. Bedrijven zijn zich bewust van de invloed die hun logistieke organisatie kan hebben op de totale logistieke, de manier van zaken doen en op de tevredenheid van hun klanten. Deze aanhoudende rationalisatie heeft tot een voortdurende zoektocht naar schaalvoordelen geleid. Parallel hieraan heeft een sterke centralisatie van productie en voorraden en sterke globalisatie plaatsgevonden.

Naarmate de productie meer en meer specialistisch wordt vindt een toenemend deel van de toegevoegde waarde buiten de eigen faciliteiten van het bedrijf plaats en is coördinatie en communicatie met partners in het logistieke network van groot belang. Een strategie die daartoe steeds meer gebruikt wordt is het zoeken naar samenwerking om de noodzakelijke voordelen in schaal en scope te bereiken. De moeilijkheid is echter het zoeken naar de juiste vorm van samenwerking en in staat te zijn om vooraf in te schatten wat de invloed is op de logistieke kosten en service. De term samenwerking kent verschillende defintiesen wordt verschillend geinterpreteerd in de context van logistieke ketens en netwerken. Gebaseerd op Schrage (1990) definieren wij samenwerking hier als volgt: "*een vrijwillig, wederzijds gedeeld proces waarin twee of meer actoren samenwerken, een gezamelijk doel hebben, een gemeenschappelijke visie, middelen delen en trachten gemeenschappelijke doelstellingen te bereiken. Kernbegrippen hierin zijn de relaties tussen de organisaties, de dwarsverbanden, gecommitteerd zijn aan het samenwerkingsverband, en het hebben van een gemeenschappelijk doel.*"

De beweegreden van een bedrijf om samen te werken zijn heel divers. Door samenwerking kunnen bedrijven: (1) *Efficiency verhoging of kostenverlaging*; potentie voor een kostenvermindering versterkt de motivatie om een partner te zoeken, (2) *Serviceverbetering*; het integreren van activiteiten in het logistieke network door samenwerking kan tot gevolg hebben dat de service verhoogd kan worden. Bijvoorbeeld door verminderde voorraad, kortere doorlooptijden en betere, tijdige en accurate informatie, (3) *Marketing voordeel*; een derde reden om in een samenwerkingsinitiatief te stappen is het bereiken van een marketing voordeel en (4) *Winstgroei of stabiliteit*; een mogelijk voordeel van samenwerken kan een verhoging in de winst zijn of het stabiliseren van de bestaande winst.

Tot op dit moment, is het ontwerpen van logistieke netwerken waarin de verschillende actoren samenwerken om hun kosten te verminderen of de service te verhogen een onderwerp dat weinig aandacht in de literatuur heeft gekregen. Dit in tegenstelling tot de aandacht die de organisatorische aspecten van samenwerking, allianties en supply chain management de laatste jaren hebben gekregen. Camarinha-Matos and Afsarmanesh (2004) stellen: "*Na een eerste periode waarin aanzienlijk is geïnvesteerd in het onderwerp samenwerking in netwerken, zijn de meeste benaderingen nog erg versplinterd en veelal gebaseerd op voorbeelden en* *anecdotisch van aard en is het nu tijd om de bestaande kennis zodanig te bundelen dat een degelijke basis gelegd wordt voor de toekomst. Een van de belangrijkste zwakheden in het gebied van samenwerking in netwerken is het gebrek aan een theoretisch kader, verenigbare paradigma's en formele modelbeschrijvingen*". De doelstelling van de studie was het ontwikkelen en demonstreren van een ontwerp en evaluatie-methodiek voor logistieke netwerken waarin de deelnemers samenwerken, gebaseerd op (1) de integrale logistieke kosten, (2) de service-eisen die vanuit de gebruikers aan het netwerk gesteld worden, (3) het type samenwerking en (4) de mogelijke schaalvoordelen die in het netwerk behaald kunnen worden. Er is een nieuwe methodiek ontwikkeld voor het ontwerpen van hubnetwerken waarin door de gebruikers wordt samengewerkt. Vertaald in een overkoepelende methodiek dat in de praktijk is getest. Binnen deze aanpak wordt op basis van de verschillende karakteristieken van het samenwerkingsverband het bijbehorende logistieke netwerk ontworpen. Hierin wordt gebruik gemaakt van bedrijfseconomische doelstellingen zoals het minimaliseren van de totale netwerkkosten en het maximaliseren van logistieke service, echter er wordt daarnaast rekening gehouden met de wijze waarop het samenwerkingsverband is georganiseerd, wie er in de samenwerking investeert, wie het risico draagt en hoe de onderlinge verhoudingen zijn.

Het networkconcept dat centraal staat is het hubnetwerk concept dat uitermate geschikt is om de stromen van verschillende verladers te bundelen en tegelijkertijd kan zorgen voor het gewenste service niveau dat vanuit de gebruikers aan het logistieke network wordt gesteld. Naast de kosten die gemoeid zijn met het hubnetwerk (handling, transport, voorraad, gebouwen, etc.) nemen we tevens de transactiekosten in de beschouwing. Deze kosten bepalen mede de deelname van een potentiële participant. De ontwerpmethodologie, die uiteindelijk kansrijke netwerkoplossingen genereerd en het daarbijbehorende ontwikkelingspad aangeeft, is nieuw en is een aanzienlijke uitbreiding op de bestaande ontwerpbenaderingen voor hubnetwerken en netwerken waarin wordt samengewerkt in het algemeen. De stap die de ontwerpmethodiek compleet maakt is de stap waarin de netwerken worden geevalueerd met behulp van simulatie. Wij maken hiertoe gebruik van bestaande simulatie technieken om de netwerkoplossingen te evalueren die voortkomen uit de ontwerpfase.

Op basis van een uitgebreide casestudy is de methodologie getest waarbij gebruik gemaakt is van daadwerkelijke ordergegevens en bedrijfsinformatie. De bevindingen, gebaseerd op deze casestudy leveren zeer bruikbare en concrete richtlijnen op voor het ontwerpen van samenwerkingsnetwerken, geven inzicht in de invloed van het ontwikkelingspad op de haalbaarheid van de oplossing en bevestigt de waarde die het evalueren van de netwerken met behulp van simulatie heeft op de acceptatie van de netwerkoplossingen. De ontwikkelde methodologie geeft de besluitvormer de kans om verschillende netwerkoplossingen in verschillende fasen van het het ontwikkelingspad te beoordelen en verschillende alternatieve samenwerkingsvormen te evalueren; essentieel op weg naar daadwerkelijke implementatie van dit type netwerk. De keuze tussen het intern organiseren, het uitbesteden of op zoek te gaan naar samenwerking is fundamenteel van aard. Bedrijven aarzelen van nature om verantwoordelijkheid op een zo belangrijk terrein als logistiek over te dragen aan een buitenstaander. De vrees voor het verlies van controle, problemen op het gebied van klanttevredenheid en het onvermogen om het system weer aan te passen indien het niet naar tevredenheid presteert, zijn redenen die door managers worden aangedragen om niet naar samenwerking te zoeken of het proces uit te besteden. Een antwoord op de vraag: "*onder welke omstandigheden beslissen bedrijven tot samenwerking met derden*?" is in deze cruciaal om in staat te zijn een logistiek netwerk te kunnen ontwerpen waarin de verschillende actoren samenwerken. Het besluit om samen te gaan werken is gebaseerd op verschillende aspecten van het verband waarbinnen dit gebeurd. Bij het modelleren van dit besluit onderscheiden wij hiertoe de volgende kenmerken:

(1) *Scope* en *doelstelling van de samenwerking*; gebaseerd op de hiërarchie in besluitvorming wordt de scope van de samenwerking bepaald (structuur van het netwerk, de invulling, planning of middelen). De doelstelling van de samenwerking is ofwel kostenefficiency, serviceverbetering, marketing voordeel of groei c.q. stabiliteit in de winst.

(2) *Type samenwerking;* wij onderscheiden drie soorten samenwerking; *Type I*, Operationele samenwerking, *Type II*, Coördinatiesamenwerking en *Type III*, Structurele samenwerking.

(3) *Specifieke investeringen*, binnen iedere vorm van samenwerking is de mate waarin de deelnemers specifieke investeringen moeten doen een zeer belangrijk determinant. Het is daarom noodzakelijk, wanneer het om modelleren van deze beslissing gaat deze investeringen voor alle actoren mee worden genomen.

(4) *Onzekerheid*, een belangrijke determinant is onzekerheid (binnen de relatie of daarbuiten) en is een zeer belangrijk bij het bepalen van de transactiekosten die dit keuzegedrag zeer sterk beïnvloeden.

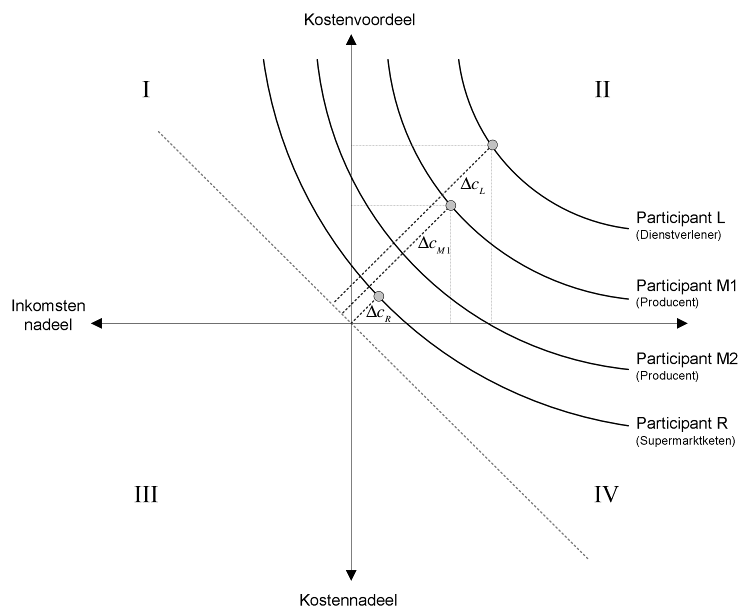
(5) *Frequentie*, een andere determinant die een grote rol speelt in de bepaling van de transactiekosten is de frequentie waarmee deze wordt uitgevoerd. Dit wordt beschouwd als een belangrijk kenmerk bezien vanuit het standpunt dat de kosten van gespecialiseerde, dure, beheersstructuren eerder gemaakt zullen worden bij transacties die veelvuldig terugkeren en daarmee gespreid kunnen worden over meerdere transacties.

(6) *Dominantie*, de mate waarin een bepaalde partij dominant is over de andere participanten en in potentie de acties en besluiten van individuen en firma's in het network kan beïnvloeden speelt een belangrijke rol bij samenwerken.

(7) *Transparantie*, verwijst naar het vertrouwen tussen de deelnemende actoren en de meetbaarheid van de kosten, de voordelen, de prestaties, etc. Indien er sprake is van een hoge mate transparantie zullen de transactiekosten aanzienlijk lager uitvallen.

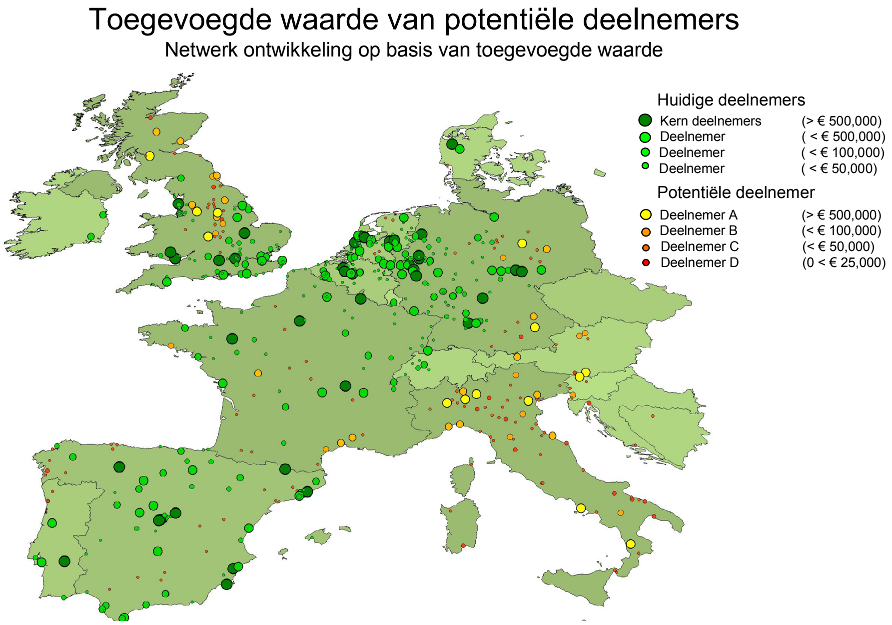
In plaats van het minimaliseren van de totale kosten in het logistieke netwerk of het minimaliseren van de kosten voor individuele bedrijven moet bij het ontwerpen van netwerken waarin wordt samengewerkt gezocht worden naar een compromis. Het is hierin noodzakelijk om rekening te houden met het type en de scope van de samenwerking. Daarnaast is het van groot belang om de verschillende rollen en onderlinge relaties in de beschouwing mee te nemen. Bovenstaande kenmerken zijn van belang bij het bepalen van het type samenwerking maar dienen daarnaast per (potentiële) participant bepaald te worden. Aangezien het besluit deel te nemen aan een samenwerkingsinitiatief een fundamentele beslissing is en de eventuele kostenvoordelen of inkomstenvoordelen bepaald worden door de rol die de participant heeft in het netwerk is het van groot belang om de rolverdeling van de participanten mee te nemen. Of de transactiekosten nu hoog of laag zijn, het effect van deze kosten op de structuur van het netwerk zijn verstrekkend en bepalen in hoge mate de deelname van de potentiële participanten. Het is daarom van groot belang om bij de keuze van een samenwerkingsstrategie, inzicht te hebben in de invloed die het type samenwerking, qua doelstelling, scope, specifieke investeringen, onzekerheid, etc., heeft op de totale kosten en uiteindelijk op de kansrijkheid van de bijbehorende netwerkoplossingen.

Samenwerkingskosten en inkomsten afweging



Figuur I: De afweging tussen de kosten en inkomsten bezien van de rol van de participant

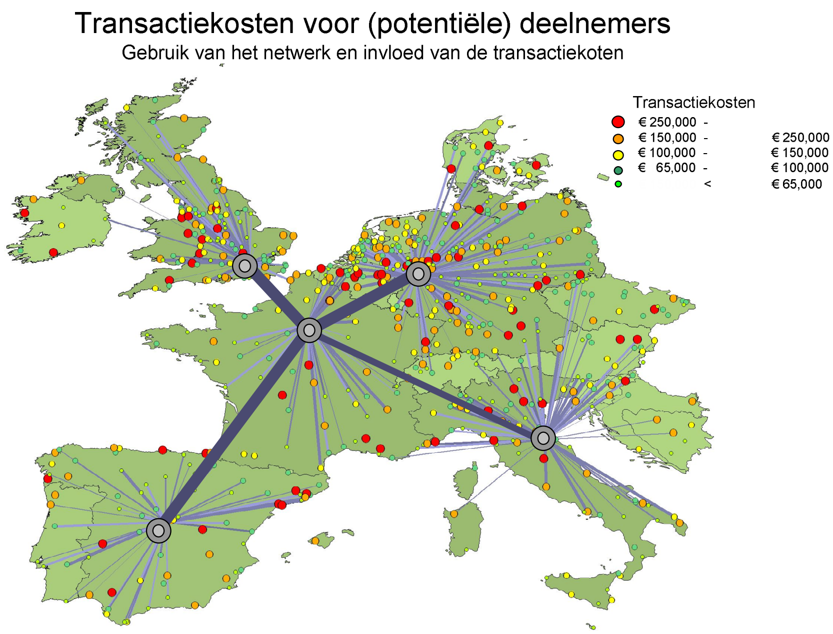
Dit inzicht is van groot belang, niet alleen vanwege de implicaties die dit heeft op de eigen logistieke en transactiekosten maar daarnaast wordt het gedrag van de partners partners ook beïnvloed. Het is immers een samenwerking. In de bovenstaande Figuur I wordt een overzicht gegeven, op twee dimensies, van de voor-en nadelen voor een viertal actoren. Er worden 2 producenten, 1 logistiek dienstverlener en 1 supermarktketen onderscheiden. In de figuur worden 4 quadranten onderscheiden. In het eerste quadrant zou samenwerken een inkomstennadeel tot gevolg hebben maar er kan een kostenvoordeel behaald worden. In quadrant III zijn er louter nadelen indien de actor deelneemt in het samenwerkingsverband. Het quadrant dat interessant is voor de actoren is quadrant II, waar zowel kostenvoordeel als inkomstenvoordeel te behalen valt. In het voorbeeld dat geschetst wordt geven de 4 curves de drempel waarde voor deelname aan het samenwerkingsverband van de 4 deelnemers aan. Bijvoorbeeld participant L (logistieke dienstverlener) heeft een aanzienlijk hogere drempel (door specifieke investeringen, onzekerheid, frequentie, etc.) dan participant R (supermarktketen) die nauwelijks in de relatie hoeft te investeren. Dit voorbeeld geeft aan dat de actoren uiteenlopend keuzegedrag zullen vertonen afhankelijk van de specifieke kenmerken van het samenwerkingsverband en daarmee ook de netwerkstructuur in hoge mate zullen bepalen. Het is duidelijk dat een besluit betreffende de structuur van het logistieke netwerk, bijvoorbeeld het aantal distributiecentra in het netwerk, het voorraadbeheer, transportplanning en aansturing sterk beïnvloedt. Om deze onderlinge afhankelijkheid tussen de verschillende niveaus in de logistiek te begrijpen is het gebruik van modellen essentieel en het vermogen om deze complexe logistieke netwerken te ontwerpen zeer waardevol. Daarnaast is de combinatie met instrumenten om netwerkoplossingen te kunnen evalueren zeer waardevol, vooral als het gaat om netwerken waarin wordt samengewerkt, waar transparantie en meetbaarheid beslissend kunnen zijn.



Figuur II: Toegevoegde waarde per (potentiële) deelnemer.

Uit de resultaten komt naar voren dat introductie van de transactiekosten in de netwerkoptimalisatie een zeer grote impact heeft op structuur van het netwerk. Door deze kosten mee te nemen kan een bedrijf belsuiten om niet deel te nemen, hoe goed de networkstructuur vanuit logistiek oogpunt ook is. Alhoewel de geïntroduceerde transactiekosten zeer conservatief zijn geschat is het effect van deze kostencomponent zeer groot en wordt de structuur drastisch aangepast. In de onderstaande figuur wordt een overzicht gegeven van de berekende transactiekosten per participant vanuit de rol die deze participant in het netwerk speelt. Dit eenvoudige voorbeeld bestaat uit verladers en een logistieke dienstverlener. De ontwikkelde methodiek maakt het mogelijk om per participant de logistieke kosten voor het hubnetwerk alternatief, kosten voor het huidige transport en de bijbehorende transactiekosten in kaart te brengen. Niet alleen voor de eindsituatie maar voor iedere willekeurige stap in het ontwikkelingspad naar deze eindsituatie. Het voordeel van deze benadering is dat de kernparticipanten bepaald kunnen worden en de transactiekosten (met name de kosten gemoeid met het zoeken naar geschikte partners) aanzienlijke verlaagd kunnen worden).

Indien de ontwerp methodiek die hier besproken wordt gecombineerd wordt met een zogenaamd *gain-sharing* instrument wordt een belangrijke aanvulling gerealiseerd, waardoor het mogelijk wordt om naast het ontwerpen van de netwerken ook het optimaliseren van de voordelen meegenomen. Dit zou voor een logistieke dienstverlener kunnen betekenen dat er gericht gezocht kan worden naar potentiele deelnemers in het network en een zeer gericht aanbieding kan doen per deelnemer en tegelijkertijd de totale winst voor het consortium kan maximaliseren. De ontwikkelde methodiek biedt de mogelijkheid om bij het ontwerpen van deze complexe hubnetwerken waarin wordt samengewerkt de haalbaarheid vooraf te kunnen toetsen en kan beschouwd worden als een belangrijke methodologische uitbreiding.



Figuur III: OVerzicht van de transactiekosten per participant.

About the Author

Bas Groothedde (1972) graduated in 1997 from the Delft University of Technology, faculty of Civil Engineering and Geosciences in the Netherlands. He worked for two years at TNO Mobility and Transport before starting part-time at the Delft University of Technology, next to his position at TNO, where he worked on the dynamics in logistics, modeling choice behavior and decision-making processes in logistics. During this period the foundations were laid for his research on collaborative logistics and transportation networks. He initiated the development of RESPONSE™, a network design and evaluation suite, and was closely involved in its development at TNO. This decision-support system is frequently used to assist companies in optimizing and restructuring their logistics network. The companies he provided with advice on their logistics network and service performance are active in the consumer electronics, perishables, retail, apparel, logistics service providers, express market, food sector, home and personal care, and foodservice. It was during his work at TNO Mobility and Transport and the projects he was involved in that he developed the basic ideas and notions that were consolidated into the dissertation Collaborative Logistics and Transportation Networks, a Modeling Approach to Hub Network Design.

He is currently a senior consultant at TNO, specialized in the design and evaluation of logistics networks. In close cooperation with organizations in the retail, consumer electronics, food, and logistics industry he initiates research, provides these companies with advice on their logistics network and focuses on the development and implementation of responsive logistics solutions. In close cooperation with the Holland International Distribution Council (HIDC), Central Bureau for Provision Trade (CBL), and the Dutch Retail Council he is involved in research on *High Responsive Networks*, *Fashion Networks*, *City Box Distribution* and robust and reliable logistics. Next to his work at TNO he is affiliated with the Delft University of Technology, and is involved in the programmes of other universities, including those in Tilburg and Rotterdam. He has written articles for journals such as *Transportation Research*, *Business Logistics*, and *Transportation Science*, for conferences such as *World Conference on Transportation Research*, *European Transport Conference*, *Operations Research International Conference,* and *System Dynamics Conference*, as well as for the *Transport and Logistics Handbook* and *European Logistics Association*

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