IMPROVING INBOUND LOGISTICS
DEVELOPING A DECISION SUPPORT MODEL TO ASSESS THE PERFORMANCE OF INBOUND LOGISTIC CONCEPTS
Summary

As a result of the shift in focus from outbound logistics, which includes the flows to the customers, to inbound logistics, an inbound logistics decision support model is developed in this research report. This model offers the user the possibility to discover the potentials that are resting in optimizing inbound logistics. The design of this model is based on the next design statement:

"Develop a model to assess and quantify the effect of inbound logistic concepts on costs"

The problem area has been scoped to the European logistic network because this guarantees the availability of a good transport network. But Danone Baby Nutrition, the problem owner, has factories worldwide, so the model can only be used for part of their factories. It was also chosen to only look at inbound flows of palletized packaging and raw materials of one factory.

Before the decision support model was developed, the supply chain of Danone Baby Nutrition and its inbound logistics process were analyzed. This led to the supply chain depicted here:

Figure 1: Current European supply chain of Danone Baby Nutrition

This supply chain will change in the future as a result of five projects that are running currently at Danone Baby Nutrition. Four of these projects are relevant for the outbound flows whereas one is influencing the inbound logistics. This is the project on Repetitive Flexible Supply that will lead to a standard production schedule for a predetermined period. As a result the demand pattern for packaging and raw materials will be better to predict in advance.
For this research the supply chain is less relevant compared to the current inbound procedure, so this is also studied and resulted in the flowchart presented below. Based on this flowchart it was concluded that Danone Baby Nutrition has a standard inbound procedure that includes a quality control for arriving goods.

With the information on the inbound process, a literature study and brainstorm sessions were performed to find suitable inbound logistic concepts. These concepts should reduce the inbound logistic costs and finally led to the following four: (1) a milk-run, (2) cross-docking, (3) Vendor Managed Inventory and (4) Just-in-Time delivery.

A milk-run can be considered as an inverse distribution run. In this case the loads are picked-up at the suppliers with one truck that drives to the factory when it has served all suppliers. By means of this consolidation, the transport costs and dock occupation are reduced and the possibility exists to reduce the inventory levels by means of a higher shipping frequency. However, disturbances are hard to include and will affect the milk-run suppliers that still have to be served after the disturbance. For a milk-run it is required that the shipments are partial loads with the same transport temperature requirement.

The concept of cross-docking means that all suppliers ship their products to one warehouse, the cross-dock facility. Here all the loads are transhipped in another truck. This truck then drives from the cross-dock facility to the factory. Again the same advantages of consolidation are valid here as was the case for the milk-run. But disadvantages exist as well in the form of the need to synchronize orders and a longer lead time. The requirements also match with the ones of the milk-run expanded with a high and stable demand for the products.

Only one supplier is involved with Vendor Managed Inventory in which the stock is no longer managed by the buyer but by the supplier. This is done because the supplier has better insight in the demand and cost components. In the end this should lead to a higher service level, lower inventory levels and reduced transportation costs. But the supplier has to be the only supplier for that material (single-sourcing requirement), supply products with a stable demand and a standard design.

Figure 2: Inbound logistic process; Red = Danone Baby Nutrition, Blue = Supplier.
With the last concept of Just-in-Time delivery, the products are delivered at the factory at the moment they are needed. In an ideal situation, this removes the need for inventory. In practice, this will result in strongly reduced inventory levels and shorter lead-times but increases the risk of production shut-down due to material shortage. To be suitable for this concept, the supplier has to be located close to the factory, be a single-sourcing supplier and his product has to have a predictable demand.

With the information on the included concepts, the inbound logistic decision support model could be developed. A flowchart of this decision support model is illustrated in figure 3. Here it can be seen that five general calculation models are used to construct the concept specific calculation models, when needed these general models are adapted to the situation of the specific concept.

The four identified concepts have to be connected to one or more suppliers before they can be evaluated, resulting in so-called unique supplier-concept-combinations. The identification of these supplier-concept-combinations is done by mapping them according to four indicators: (1) drop-size, (2) delivery frequency, (3) transport condition and (4) whether the supplier is a single-sourcing supplier or not. The results of this identification process form the input for the calculation models of the decision support model.

The output of the decision support model is the performance of the identified supplier-concept-combinations with regard to the transport, inventory, handling and ordering costs and invested capital. The final ranking of the supplier-concept-combinations is based on the reduction of total inbound logistic costs, which is the sum of the four cost components, or the decrease in invested capital.
capital.

Other companies in different industries can apply the developed decision support model on their inbound logistics as well as long as they use road transport for the inbound flows. Downsides of the model are the high number of parameter values that have to be collected for a reliable result and that there is no indication included for the size of unexpected costs. It should also be kept in mind that due to the developments in the logistics area always new concepts arise. Since the model is not perfect, there are two major possible improvements identified: (1) an equation to predict the transport price per kilometer as a function of the distance and type of truck used and (2) criteria on flexibility and service level should be included to improve the decision process.

In the end a case study is performed for the Opole factory of Danone Baby Nutrition. The mapping and supplier-concept-combinations identification procedure in the case study led to a map with 68 of the 161 suppliers and a total of eight supplier-concept-combinations were identified. These supplier-concept-combinations, in which the suppliers are connected to the four concepts, can be seen in figure 4 on below.

![Map of supplier-concept-combinations identified for the Opole factory](image)

Figure 4: Map of supplier-concept-combinations identified for the Opole factory

With these eight supplier-concept-combinations as input for the inbound logistics decision support model, their effects on total costs and invested capital could be calculated. One comment has to be made on the cross-dock cluster because the supplier in the northern part of the Netherlands is excluded (supplier linked to VMI 3). This led to the output results of the decision support model presented on the next page.

---

1The exact same model as is developed in this research.
Table 1: Improved SCC results on costs in euro

<table>
<thead>
<tr>
<th>SCC</th>
<th>Transport cost</th>
<th>Inventory cost</th>
<th>Handling cost</th>
<th>Ordering cost</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMI 3</td>
<td>-5700</td>
<td>800</td>
<td>-100</td>
<td>-1600</td>
<td>-6600</td>
</tr>
<tr>
<td>Milk-run 1</td>
<td>-1000</td>
<td>-2700</td>
<td>-100</td>
<td>1100</td>
<td>-2600</td>
</tr>
<tr>
<td>Milk-run 2</td>
<td>-2700</td>
<td>-1300</td>
<td>-100</td>
<td>1800</td>
<td>-2300</td>
</tr>
<tr>
<td>VMI 1</td>
<td>500</td>
<td>-200</td>
<td>0</td>
<td>-700</td>
<td>-400</td>
</tr>
<tr>
<td>VMI 2</td>
<td>4400</td>
<td>-500</td>
<td>0</td>
<td>-700</td>
<td>3300</td>
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<tr>
<td>Cross-dock 1</td>
<td>42400</td>
<td>-1800</td>
<td>3600</td>
<td>2200</td>
<td>46400</td>
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<tr>
<td>JIT 1</td>
<td>57100</td>
<td>-1800</td>
<td>800</td>
<td>-200</td>
<td>55900</td>
</tr>
<tr>
<td>JIT 2</td>
<td>63400</td>
<td>-2100</td>
<td>700</td>
<td>-900</td>
<td>61100</td>
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</table>

Table 2: Improved SCC results on invested capital in euro

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<th>Invested capital</th>
<th>SCC</th>
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<td>VMI 3</td>
<td>4500</td>
<td>VMI 2</td>
<td>-2700</td>
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<tr>
<td>Milk-run 1</td>
<td>-15400</td>
<td>Cross-dock 1</td>
<td>-3200</td>
</tr>
<tr>
<td>Milk-run 2</td>
<td>-7500</td>
<td>JIT 1</td>
<td>-10400</td>
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<tr>
<td>VMI 1</td>
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<td>JIT 2</td>
<td>-12200</td>
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</table>

These tables present the performance of the supplier-concept-combinations with respect to the current situation. For the current situation the following values for the cost components and the invested capital have been calculated.

- **Total cost**: €295700
  - Transport cost: €229100
  - Inventory cost: €45300
  - Handling cost: €11300
  - Ordering cost: €10000

- **Invested capital**: €264800

The savings obtained by the eight supplier-concept-combinations are not in line with the expectations of the researcher and are not large enough to stimulate an implementation of one of them. This is especially caused by the great importance of the transport costs and the fact that an increase of the transport costs have to be compensated by reduced inventory cost. As a result of an assumption on the pallet value, the inventory costs are not decreased enough to yield a positive total cost reduction. So before a final conclusion can be drawn for the case study, Danone Baby Nutrition first has to: (1) gather more accurate data on the input parameters and especially for the weighted average pallet value and (2) verify the results of the transport cost calculation model with a tender. However, the decision support model proves to be working and useful to assess possible savings on inbound logistics.

Besides the recommendation to gather more accurate data and verify the transport cost calculation, Danone Baby Nutrition should also look for other concepts the improve their inbound logistics. These concepts can be included in the decision support model by building them with the general calculation models. Since the model has now only been applied at one factory, it is advised to use the model for other factories as well.
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<td>Ordering efficiency</td>
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<td>$C_{cycle}$</td>
<td>Annual cycle stock holding cost</td>
<td>€</td>
</tr>
<tr>
<td>$C_{handling}$</td>
<td>Total yearly handling cost</td>
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<td>Empty kilometers after unloading</td>
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<td>$H$</td>
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<td>$n_{pallets}$</td>
<td>Number of pallets that arrive per year</td>
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<td>$n_{ship/order}$</td>
<td>Number of shipments per order placed</td>
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<td>$n_{stops}$</td>
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15
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<td>Number of suppliers</td>
<td>-</td>
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<td>$n_{trip}$</td>
<td>Number of trips on a lane per year</td>
<td>-</td>
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<tr>
<td>$n_{trucks}$</td>
<td>Number of arriving trucks per year</td>
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<td>$p$</td>
<td>Supplier's annual production volume</td>
<td>pallet</td>
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<td>$p_c$</td>
<td>Cost of cross-docking one pallet</td>
<td>€/pallet</td>
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<td>$pcarrying,S$</td>
<td>Supplier’s carrying cost per euro of inventory per year</td>
<td>% of pallet value</td>
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<td>Carrying cost per euro of inventory per year</td>
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<td>$pdocking$</td>
<td>Cost for docking a truck</td>
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<td>Transport price per kilometer</td>
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<td>Ordering cost per order</td>
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<td>Supplier’s cost per shipment release</td>
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<td>Supplier’s physical storage cost per pallet location per year</td>
<td>€/pallet</td>
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<td>$Q$</td>
<td>Quantity ordered</td>
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<td>$Q_c$</td>
<td>Current optimal production quantity</td>
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<td>$Q_{VMI}$</td>
<td>Optimal production quantity under VMI</td>
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<td>$\sigma_{DL}$</td>
<td>Standard deviation of demand during the lead time</td>
<td>pallet</td>
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<td>$S$</td>
<td>Supplier's production setup cost</td>
<td>€</td>
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<td>$S_h$</td>
<td>Hourly salary of an inbound warehouse employee</td>
<td>€/hour</td>
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<td>Hourly salary of a buyer</td>
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<td>Average driving speed of a truck</td>
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<td>Safety stock level</td>
<td>pallet</td>
</tr>
<tr>
<td>$t_{check}$</td>
<td>Time required to check a truck and transport documents</td>
<td>minute</td>
</tr>
<tr>
<td>$t_{cross}$</td>
<td>Time needed to arrange a cross-dock</td>
<td>minute</td>
</tr>
<tr>
<td>$t_{drive}$</td>
<td>Maximum hours that can be driven in one day</td>
<td>hour</td>
</tr>
<tr>
<td>$t_q$</td>
<td>Quality control duration</td>
<td>day</td>
</tr>
<tr>
<td>$t_{transit}$</td>
<td>Transit time</td>
<td>day</td>
</tr>
<tr>
<td>$t_{unload}$</td>
<td>Time required to unload, check, label and store incoming pallet</td>
<td>minute</td>
</tr>
<tr>
<td>$t_m$</td>
<td>Time needed to arrange a milk-run</td>
<td>minute</td>
</tr>
<tr>
<td>$t_o$</td>
<td>Overlapping time of replenishment actions</td>
<td>day</td>
</tr>
<tr>
<td>$t_p$</td>
<td>Production time per delivered quantity</td>
<td>day</td>
</tr>
<tr>
<td>$U$</td>
<td>Utilization of a product/material</td>
<td>-</td>
</tr>
<tr>
<td>$v$</td>
<td>Volume shipped</td>
<td>pallet</td>
</tr>
<tr>
<td>$V$</td>
<td>Total annual demand</td>
<td>pallet</td>
</tr>
<tr>
<td>$v_c$</td>
<td>Current average drop-size</td>
<td>pallet</td>
</tr>
<tr>
<td>$v_{cross}$</td>
<td>Cross-dock drop-size</td>
<td>pallet</td>
</tr>
<tr>
<td>$v_{FTL}$</td>
<td>Minimum volume of a full truckload</td>
<td>pallet</td>
</tr>
<tr>
<td>$v_{JIT}$</td>
<td>Just-in-Time drop-size</td>
<td>pallet</td>
</tr>
<tr>
<td>$v_m$</td>
<td>Milk-run drop-size</td>
<td>pallet</td>
</tr>
<tr>
<td>$\bar{v}_{pallet}$</td>
<td>Average pallet value</td>
<td>€/pallet</td>
</tr>
<tr>
<td>$v_{sync}$</td>
<td>Synchronization volume</td>
<td>pallet</td>
</tr>
<tr>
<td>$v_{truck}$</td>
<td>Maximum number of pallets that fit in a truck</td>
<td>pallet</td>
</tr>
<tr>
<td>$v_{VMI}$</td>
<td>Optimal replenishment quantity under VMI</td>
<td>pallet</td>
</tr>
<tr>
<td>$x$</td>
<td>Cartesian x grid coordinate</td>
<td>-</td>
</tr>
<tr>
<td>$y$</td>
<td>Cartesian y grid coordinate</td>
<td>-</td>
</tr>
<tr>
<td>$z$</td>
<td>Number of standard deviations</td>
<td>-</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction

Logistical processes and networks are constantly evolving and improved in order to gain performance. In the past the focus on gaining performance was mostly on outbound logistics that is concerned with transporting the finished products to the customers as efficient as possible with regard to costs, service level and flexibility. Recently companies have shifted their point of attention to the inbound logistics which are the flows from the suppliers to the buyers. One of these companies that are looking at inbound logistics is Danone Baby Nutrition. In 2008 they performed a study on the possible benefits of Factory Gate Pricing, a concept in which the buyer arranges the product pick-ups at the supplier.

This research will continue in this direction but with a broader perspective on inbound logistics. As a result of this wider approach, four different inbound logistic concepts are identified and included in the design of an inbound logistics decision support model. This model serves as a tool to assess the opportunities for Danone Baby Nutrition on inbound logistics for its European network. But it can also be used to calculate the costs of the current situation.

The development of the inbound logistics decision support model will be the center of attention in this research and results in a spreadsheet model that every company can use to quantify potential benefits on inbound logistics. Before this model can be constructed, the supply chain and inbound logistics process of Danone Baby Nutrition are analyzed. Based on this analysis the researcher identified four promising and frequently used concepts. Paying attention to the advantages, disadvantages and requirements of these concepts makes it possible to develop a procedure based on mapping the suppliers that enables a classification of which suppliers are suitable for a certain concept. This creates the basis for the input data needed to use in the decision support model.

The advantage of the decision support model that is designed in this research is that it is made out of general calculation models. These general components are adapted to the specific needs of the concepts to create concept specific performance models. The quantified results of the performance assessment models enables the user to rank the concepts.

To show the usability of the model developed a case study is performed for one factory of Danone Baby Nutrition in which the complete process is carried out step by step. After this case study the conclusions and recommendations are presented. Before this can be done, first the design problem has to be defined in the next chapter.
Chapter 2

Problem definition

Whereas it was in the introduction already revealed that an inbound logistics decision support model is being developed in this research, a problem definition still has to be presented. This problem definition with sub-questions, scoping issues, deliverables, methodology and the research report structure are presented in this chapter.

2.1 Design problem

Improving the inbound logistics at Danone Baby Nutrition is the general topic of this research with a special focus on cost reduction. The demand for this focus is from within Danone Baby Nutrition as a result of their goal of reducing the inbound logistic costs. Currently there is no clear overview of how this objective can be reached and what potential rests in optimizing the inbound logistics at Danone Baby Nutrition. Therefore a decision support model is developed in this research that enables the identification and assessment of potential savings on inbound logistics. Based on the output of the decision support model Danone Baby Nutrition can decide what steps will be taken. This leads to the following design problem:

"Develop a model to assess and quantify the effect of inbound logistic concepts on costs"

Before the model is fully developed, a number of intermediate steps have to be taken. These steps will become clear in the next sections that will describe the deliverables, methodology and sub-questions.

2.2 Scoping

The design problem is presented in a general manner and is only limiting the research area by stating that the focus is on the costs. However it is not intended to develop a decision support model that can be applied in all situations so therefore a number of scoping decisions are presented in this section. These decisions can be split in two categories, the ones that are applicable on the model development and the ones that are used when the model will be applied at Danone Baby Nutrition.

The first scoping decision that is made is to develop the model as a spreadsheet model by using Microsoft Excel. This guarantees that the model is compatible with the current software resources available at the problem owner, Danone Baby Nutrition.

When considering the solution space for the decision support model development, it is chosen to use the European logistic environment that includes the availability of a good network to transport goods from their origin to their destination. When applying this model for Danone Baby
Nutrition this directly means that the model is only intended for their European factories and not for the ones that are located in the rest of the world.

Despite the fact that a multinational company such as Danone Baby Nutrition has multiple factories located on one continent, it was chosen to only investigate the effects of the identified concepts on the inbound logistics of one factory. This scoping decision is justified by the fact the each factory can be considered as a separate company because they are responsible for their own purchasing process and there is currently no coordination with other factories. The only coordination that exists is that the selection of large suppliers by the headquarters of Danone Baby Nutrition. So concepts that include multiple factories at the same time are scoped out.

The model will only focus on the data that is put in and will thus be applied to the current supplier base. The reason why this is mentioned is because the supplier portfolio might change over the years, thereby influencing the effect of a concept.

In order to be able to combine goods, the model will be only suitable for palletized goods due to the simple reason that it is rather difficult to combine multiple liquids in one tank truck. Specifically for Danone Baby Nutrition this is further scoped down to only palletized inbound raw materials and packaging materials and thus excluding products such as detergents for cleaning machines.

So in the end the scope is defined as:

- Spreadsheet based model using Microsoft Excel;
- European logistic environment;
  - For Danone Baby Nutrition: only the European network and factories
- Inbound logistics of one factory at the time;
- Palletized shipments
  - For Danone Baby Nutrition: only raw materials and packaging

The scoping is clear now so that the deliverables can be listed in the next section.

### 2.3 Deliverables

When looking in more detail at the design problem it can be seen that two individual parts can be identified. The first one is the development of a model to assess and quantify the effects of optimizing inbound logistics. The second part is the use to model on a real-life situation, which will be at Danone Baby Nutrition in this case, to assess the impact. A third, less obvious part, is the identification of the concepts that can be used for the inbound logistic optimization. Before these concepts can be identified and the model can be designed, the current logistics situation at Danone Baby Nutrition has to be investigated. So in total four deliverables are present in this research report:

1. **Description of the current inbound logistics situation at Danone Baby Nutrition**
   *For this deliverable the current supply chain of Danone Baby Nutrition is described, together with the trends that change this supply chain in the future and a more detailed look at the inbound logistic process.*

2. **A description and an overview of possible inbound logistic concepts**
   *This overview will be the result of a short study to identify frequently used concepts on inbound logistics and contains a description with the advantages, disadvantages and constraints of each concept that is included.*
3. A decision support model that determines the concept ranking and quantifies the impacts. By using the concepts that have been identified different models can be developed to assess their performance according to certain criteria. Combining all these models with a selection tool will lead to the decision support model.

4. Application of the model in a case study. To illustrate and validate the model, a case study is performed for a factory of Danone Baby Nutrition thereby giving an impression of possible cost savings.

These four deliverables are related to each other and have to be solved in certain order. This specific order will be determined and described in the next section that presents the methodology of this research.

2.4 Methodology

Of the four deliverables presented in the previous section, the one that includes constructing the decision support model is the most important one since this is a direct result of the design problem stated in section 2.1. However before this model can be presented a structured approach has to be selected.

Literature presents a number of different rational decision models/methods as can be seen in appendix A. The methods presented in this appendix are combined and summarized to the following six steps for developing the decision support model:

- **Step 1** Define the problem
- **Step 2** Analyze the environment
- **Step 3** List possible inbound logistic concepts
- **Step 4** Define selection criteria and constraints
- **Step 5** Evaluation of concept performance according to selected criteria
- **Step 6** Ranking of inbound logistic concepts

These six steps however are not enough for this research since the inbound logistics concepts have to be connected to one or more suppliers of a factory. And although evaluating the performance of such combinations is mentioned as one step, calculation models are required in order to present quantitative results. The remainder of this section will now focus on introducing the required extra steps as well as the research methodology of individual parts.

After the first step of defining the problem, the problem environment has to be investigated. Analyzing this environment will result in a description of the Danone Baby Nutrition division and the way inbound logistics are currently managed. This is done by both desk and field research, meaning that information is gathered by available documentation on Danone Baby Nutrition, interviews with employees and a factory visit to experience the process.

When the environment is known, the solution space is also known and thus the step to listing the possible inbound logistic concepts can be made. Scientific literature (both articles and books), websites and brainstorming will be used in the desk research for possible concepts. Finalizing this step will result in the second deliverable, a description and an overview of possible inbound logistic concepts. In the end this will also lead to a list of qualitative constraints for each concept that determine the needed conditions before a concept can be applied. These constraints can be quantified by using the calculation models that are developed in step 5. Before step 5 can be
performed, step 4 has to be completed by selecting the criteria that are used for evaluation. These criteria will be selected together with an employee of Danone Baby Nutrition.

In step 5 the concept performance is assessed, this performance evaluation will be split in two parts. The first part will be concerned with identifying the supplier-concept-combinations\(^1\) (SSC's). The quantitative constrains of the concepts will be input for the selection process. After the identification the calculation models that are developed in this report, can calculate the effects with respect to the selected criteria. This is the second part of the performance evaluation.

In the last step a ranking of the supplier-concept-combinations is made based on the selected criteria. This ranking enables Danone Baby Nutrition to decide what actions will be performed. This will be explained in more detail later on. So all steps have been introduced and this leads to a number of sub-questions and problems that have to be solved first before the main design problem can be answered. These sub-questions and problems will be introduced in the next section.

### 2.5 Sub-questions and design problems

In the previous section a number of steps in the process of constructing the decision support model have been presented. As a result there are a number of sub-questions and smaller design problems that have to be answered/solved in order to be able to design the complete model. These sub-questions and design problems make it possible to perform the development step by step in a structured manner. In the end this leads to the following questions and problems:

**Question 1** How does the current supply chain looks like at Danone Baby Nutrition?

**Question 2** What future logistic developments are expected at Danone Baby Nutrition?

**Question 3** What is the current inbound logistic procedure at Danone Baby Nutrition?

**Question 4** Which logistical concepts can be used to reduce the inbound logistic costs and what are their advantages, disadvantages and constraints?

**Question 5** How can the selection process be described on a high-level and what criteria will be used?

**Question 6** Develop calculation models that assess the concept performance with respect to the criteria;

**Question 7** What is the area of application of the model, what are its limitations and possible improvements?

**Question 8** What results can be expected for a selected factory of Danone Baby Nutrition?

Answering these questions and solving the problems piece by piece will eventually make it possible to construct the decision support model that was presented in section 2.1. These questions and problems, in combination with the six steps of the previously introduced rational decision model, are the backbone of this report. So therefore the structure in the next section will be related to these components.

\(^1\)For each concept only a subset of suppliers is suitable for application, so these combinations of concepts with suppliers have to be identified first.
2.6 Report structure

Before the conclusions and recommendations can be presented with regard to the design problem, all previous mentioned sub-questions have to be answered thereby completing the six steps of the rational decision-making model. Combining this all together results in the report structure as presented in figure 2.1 below.

![Report structure diagram]

Figure 2.1: Report structure based on the methodology and sub-questions
Chapter 3

Danone Baby Nutrition and inbound logistics

The goals of this research, as mentioned in the previous chapter, is to design a decision support model to assess the reduction of the inbound logistic cost of Danone Baby Nutrition, part of the company Danone. The first step after the problem statement is to analyze the environment and will be done in this chapter. First Danone as a company will be shortly introduced by briefly presenting the history after which the divisions are described. In the end more attention is paid to the division of Danone Baby Nutrition, its supply chain and the current inbound logistic process.

3.1 The company Danone

Danone is a worldwide operating food company that focuses on products that bring health to their customers. This is also visible in their mission statement:

"Bringing health through food to as many people as possible"

For fulfilling this mission Danone has 147 production plants and approximately 80,000 employees’ worldwide in over 120 countries. The 15 billion euro sales in 2009 generated by four divisions give an impression of the size of Danone. Danone has a leading position in four areas with the following divisions: fresh dairy products (no. 1 worldwide), water (no. 2 on the packaged water market), baby nutrition (no. 2 worldwide) and medical nutrition (no. 1 in Europe).

A long history has passed on before reaching these accomplishments and therefore the next paragraph will shortly present the history of the Danone.

3.1.1 A brief history of Danone

In 1919 Danone was founded by Isaac Carasso in Barcelona, he made the first Danone yoghurt that was sold in pharmacies. Ten years later in 1929, Isaac’s son Daniel created the brand Danone and launched Danone in France. Due to the war the Carassos fled to the United States where they set up Dannon Milk Products Inc. in 1942. After the war the Carasso family returned to France to merge with Gervais (Gervais Danone) in 1958 thereby moving into new types of fresh dairy products.

On the other hand Antoine Riboud establishes and directs BSN in 1966, a French glass and packaging company. But during the following years the focus of BSN shifts from containers to food and beverages therefore acquiring Evian, Kronenbourgh and Blédina, and becoming the only food group totally focused on healthy food.
In 1972 Daniel Carrasso and Antoine Riboud meet each other, leading to the merger of BSN and Gervais Danone to become Europe's leading food company under the name of BSN-Gervais Danone, led by Antoine Riboud. A remarkable moment in the history of Danone is the speech of Antoine Riboud at the national congress of the French employers' association in Marseille in 1972. This speech was a founding moment for Danone's commitment to the environment in which it operates and was summed up in the phrase "a business does not exist in a no man's land". What Antoine Riboud thus defined was what has been described as a dual project, combining commitment to business success with concern for people and the planet.

The story continues with a number of acquisitions to strengthen the position of BSN-Gervais Danone which is renamed in 1994 to Groupe Danone. In 1996 Antoine's son Frank Riboud takes over the business, leading to a re-focus on three core businesses with high growth potential - Fresh Dairy Products, Waters and Biscuits - and steps up the geographical expansion which is in 1996 mostly focused on Western Europe (80% of the sales).

In order to refocus on the health-through-food principle, the Dutch company Royal Numico N.V. is acquired and the biscuit line is sold in 2007. Royal Numico N.V. was founded in Zoetermeer (the Netherlands) in 1896 under the name "Stoomzuivelfabriek (EN: Steamdairyfactory)" by the brothers van der Hagen. Only five years later in 1901 the name Nutricia was adopted, which then obtained Cow&Gate in 1981. After acquiring Mulipa and SHS in 1995 Nutricia changed the name into Royal Numico in 1997 (Royal designation was assigned in 1996). The name Numico originates from the three main brands (NUtricia, MIlupa, COw&Gate). Also Dumex and Mellin are acquired by Royal Numico N.V. in 2005 before the acquisition by Groupe Danone in 2007. This is the birth of the Baby Nutrition Division and the Medical Nutrition Division.

One year after the acquisition of Royal Numico N.V. Danone is restructured, resulting in the current four business lines - Fresh Dairy Products, Waters, Baby Nutrition and Medical Nutrition. The next section will tell more about these divisions.

3.1.2 The four divisions of Danone

As mentioned in the previous paragraph, Danone consists of four divisions, Fresh Dairy Products, Waters, Baby Nutrition and Medical Nutrition. The largest of them in turnover is the Fresh Dairy Products division with a 57% share in the total turnover of 2009. This division has more than 31.000 employees and 55 plants worldwide. The main brands of this business unit are Actimel, Activia, Danonino, Danacol, Vitalinea and Danette.

Another division that has its roots in Danone is the Waters division with a 17% share in the turnover (see figure 3.1). Product brands as Bonafonte, Aqua, Evian, Volvic, Font Vella, Lanjaron, Villavicencio, Villa Del Sure and Mizon find their way to the market through 84 plants around the world and the division has around 33.000 employees.

By the acquisition of Royal Numico two new departments became part of Danone, Baby Nutrition and Medical Nutrition. The latter one has a turnover share of only 6% in 2009, but realized a growth of 11.4%. For the operation of this division there are 3 production sites and just over 3500 employees. Main brands of this unit are Nutricia, Neocate, Fortisio, Nitrini and Nutrison.

The last but third-largest division is the one of the Baby Nutrition. Well known brands are Dumex, Aptamil, Blédina, Nutrilon, Cow&Gate, SGM, Mellin, Bebelac and Gallia. Worldwide 21 plants are producing products for this department with a staff of more than 11.100 Danoners.

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Noticeable in the main branding of the four divisions is the conservation of original brand names after the acquisitions described in the history of Danone in the last paragraph. Reasons for this are the brand awareness and the long history of the brands in the countries they are sold. A total overview of the shares in the total turnover of 2009 is presented in figure 3.1.

![Figure 3.1: Share of the divisions in the total turnover of 2009](image)

To give an impression about the presence of the factories of all divisions worldwide, a map is included. However this map is from 2008 while the numbers presented in this section are from 2009 so there is a little bias (147 plants in 2008 versus 163 plants in 2009).

![Figure 3.2: Worldwide map of Danone plants (September 2008)](image)

After this introduction of the four divisions of Danone, it is time to spend more attention to the problem owner in the next section.

### 3.2 Danone Baby Nutrition

As was already mentioned, Danone Baby Nutrition is the problem owner so therefore this division has to be described in more detail. This will not be done by presenting all kind of figures about the division since this is not extremely relevant for this study on their inbound logistics. Thus the focus will now be on their logistics, first starting by describing the supply chain and developments in this supply chain. When this information is presented, a closer look will be taken on the current inbound logistics process at Danone Baby Nutrition.
3.2.1 Current supply chain and developments

Despite that this research focuses on inbound logistics, the complete supply chain of Danone Baby Nutrition, from its suppliers to the final consumers, will be described for a better understanding of the flow of products and materials. This will be done for the European market where 11 of the 21 factories of Danone Baby Nutrition are located and is in line with the scoping presented in the previous chapter. Because area of logistics is constantly evolving, a summary of the developments in their supply chain is presented.

The supply chain of Danone Baby Nutrition

To describe the supply chain of Danone Baby Nutrition from its suppliers to the consumers, first all components will be introduced after which a supply chain diagram is presented. To have a better understanding of the outbound network of Danone Baby Nutrition, a map of their factories and distribution warehouses will be depicted.

When considering the sourcing of materials used for production by manufacturing plants\(^1\) of Danone Baby Nutrition, two major types of suppliers can be identified: (1) packaging suppliers and (2) raw material suppliers. The raw material suppliers provide the material needed for the final product whereas the packaging suppliers provide, as the name already suggests, the packaging of the final product (examples are cans, bottles but also shrink foil and carton boxes). A third type of supplier can be identified as well within Danone Baby Nutrition, the semi-finished goods supplier that produces the base powder that is used for the producing powder based products. The semi-finished goods suppliers produce also finished goods next to the base powder.

Depending on the destination, the finished goods are produced on a make-to-order basis (pull-based) initiated by the sales unit\(^2\) or push-based. After production the finished goods have to be stored for at least 5 to 10 days, this period is used to perform a quality check that is necessary because of the high safety obligations on baby food. However the location of this stock can be either at the premises of the factory or at a warehouse located close to the factory\(^3\).

\(^1\)Factories are called Supply Points within Danone Baby Nutrition.

\(^2\)An office of Danone Baby Nutrition located in the country for which it is responsible for the sales.

\(^3\)A warehouse that is located close to a factory is called a primary warehouse within Danone Baby Nutrition.
When the products are released after the quality check, they are shipped to national distribution warehouses. In figure 3.3 on the next page, the factories and secondary warehouses of Danone Baby Nutrition are mapped to give an impression of the possible flows from the factories to these warehouses. It should be noted that there are also third-party manufacturers that produce finished goods and ship them directly to the national distribution warehouses. From these warehouses the products are sold over one of the five consumer channels. The five distribution channels to the consumer that are used by Danone Baby Nutrition are:

1. **Modern trade in-store sales**: The products are shipped to one or more distribution centers of large concerns (modern trade) such as Albert Heijn in the Netherlands after which they transported to and sold in their stores;

2. **Modern trade internet sales**: Modern trade is also offering a direct link from their distribution center to the consumer by internet sales;

3. **Traditional trade in-store sales**: Shops that are not part of a large concern are classified as traditional trade and are supplied directly with the products.

4. **Baby stores**: Also baby stores such as Prenatal in the Netherlands are supplied directly.

5. **Hospitals and pharmacies**: Danone Baby Nutrition products are also reaching the consumers via hospitals and pharmacies that buy the products at wholesalers.

All components between the suppliers and the consumer are described. In order to get a clear image of the flow, a supply chain diagram is presented in figure 3.4. A traditional visualization of this supply chain can be found in appendix B.

![Supply chain diagram](image)

**Figure 3.4: Current European supply chain**

Logistics is continuously changing so therefore also the developments of the supply chain within Danone Baby Nutrition will be shortly listed in the next subparagraph.

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4The so-called secondary warehouses
Developments: The supply chain of the future

Danone Baby Nutrition is constantly improving its supply chain thereby affecting the supply chain structure that was presented before. So these changes are listed here and shortly explained.

In total five projects are identified that influence the supply chain:

1. **Repetitive Flexible Supply**: A project in which the production schedules are made repetitive for a pre-determined period and thus results in a more push-based oriented supply chain from the factories onwards and a more predictable demand pattern of raw materials and packaging;

2. **Direct shipments**: Shipping the finished goods directly from the factory to the national distribution centers without (temporary) storage in a primary warehouse located near the factory;

3. **Quarantine removal**: Ship the products as fast as possible after production without waiting on the quality sample analysis;

4. **Contracts with suppliers**: Converting 'total price' DDP\(^5\) contracts into DDP contracts that are stating a separate product and a transport component;

5. **Direct sales**: Sell products directly from secondary warehouses to the consumers via internet thereby directly competing with modern trade concerns.

When considering these projects and their effect on the previously illustrated supply chain, it results in a new supply chain that excluded the primary warehouses and includes a direct sales channel from the secondary warehouses to the consumers. In the end this results in the supply chain depicted in figure 3.5, again the traditional representation can be found in appendix B.

\(^5\)Delivery Duties Paid incoterm, this means that the supplier is responsible for arranging transport and bears the risk during transport, see appendix C.
Four of the five stated projects are focussed on outbound logistics and thus out of scope for the remainder of this report. Only the project on Repetitive Flexible Supply is affecting inbound logistics in a positive manner by creating more predictable demand patterns. Despite that this project is not influencing the inbound network structure it will be kept in mind for the development of the decision support model. Before this model can be developed, the inbound logistics process will be investigated in the next paragraph.

### 3.2.2 Inbound logistics at Danone Baby Nutrition

Before inbound logistic concepts can be identified for the development of the decision support model, the current inbound logistics have to be described up to the point of storage in the inbound warehouse. This will be done in this paragraph and is based on a visit to the factory in Fulda, Germany.

Before the complete process is explained, first a process diagram of the inbound logistics is presented in figure 3.6. In this figure it can be seen that the whole process starts with the generation of a demand forecast in every country by the sales unit in that particular country. Based on all these forecasts, a production planning can be made that is translated in a demand planning for raw materials and packaging. When a software package as SAP is present, the translation will be done by this package, which also monitors the inventory levels and the inventory locations in the factory. When this is not available, this will be done manually.

![Inbound logistic process](image)

**Figure 3.6: Inbound logistic process; Red = Danone Baby Nutrition, Blue = Supplier.**

So based on the inventory levels and the demand for raw materials and packaging, the orders can be placed at the suppliers to obtain the required goods. When this is a standard product that is on stock at the supplier, it will be shipped directly, if there is no stock available it will first be produced before shipping. Since the large majority of the contracts with the suppliers are DDP contracts, meaning that the supplier is responsible for arranging transport and bears the risk during the transport\(^6\). The supplier also has to reserve a time slot in the dock planning of the factory to deliver the goods.

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\(^6\)See appendix C.
At the moment the truck arrives at the factory, it will be unloaded and checked for damage on the goods. Also the truck itself will be checked on criteria such as humidity in the trailer, condition of the truck and the smell inside the trailer. When it is all approved and the good are not damaged, they will be stored in the inbound warehouse. However when the products are damaged, it will first be check whether they can still be used. If not they are either returned to the supplier or destroyed, otherwise the usable part is still stored in the inbound warehouse after all.

Since there are high quality standards in the baby food industry, the inbound materials have to be checked on their quality. This can be done in two ways, either by a quality certificate or by a quality control performed at the quality department of the receiving factory. In the latter case a sample is taken and submitted to a number of quality tests, if the product passes these tests it is released so that it can be used for production. If it fails to pass these tests it is again either destroyed or send back to the supplier. Another option is that the supplier already performs these quality tests and sends a quality certificate, confirming that the product meets the requirements. It still happens that products are shipped before these tests are finalized and thus the option exists that the product does not meet the required standard. In this case the standard procedure will follow (send back or destroy). The method with the quality certificate is mostly used for semi-finished products manufactured by Danone Baby Nutrition themselves.

The only part of the inbound process that has not yet been introduced is the financial process. After the truck arrives, a notification is send to the supplier that the goods have reached their destination. The supplier then sends an invoice that is paid by Danone Baby Nutrition after the payment term, which is most of the times 90 days.

The elaborated flowchart of the inbound logistics process can also be simplified by merging multiple components that are concerned with the same activity. Doing this results in the following simplified flowchart:

![Simplified inbound logistic process flowchart](image)

**Figure 3.7: Simplified inbound logistic process; Red = Danone Baby Nutrition, Blue = Supplier**

Based on this simplified flowchart it can be concluded that Danone Baby Nutrition has a standard inbound procedure, meaning that there are no special agreements or automatic linkages between the buyer and the supplier. The only extra component is the quality control, but this is present at a lot of companies as well and therefore considered not to be so special after all.

This standard process will be the starting point for the construction of the decision support model. However, first the possible concepts that can be used to improve the inbound logistic performance with respect to cost have to be identified. This will be done in the next chapter.
Chapter 4

Identification of inbound logistic concepts

In the previous chapter the company Danone Baby Nutrition and the current inbound logistic process were described. There it was concluded in the end that Danone Baby Nutrition has a standard procedure of ordering and shipping products. Following the steps of the decision support model presented in chapter 2, the next step is the identification of possible concepts that can be used to obtain cost savings. So that will be done in this chapter as part of the search for a more optimized flow of inbound goods.

Reaching the goal of reduced inbound logistic costs can be realized in various ways, ranging from internal process improvement to a redesign of the complete logistic network. This chapter contains a small description of the methodology used to find possible concepts after which the identified concepts are elaborately discussed.

4.1 Identification of inbound logistic concepts

Before a decision can be made on which concept performs best compared to others, these concepts have to be found and listed first. The researcher uses the results of a brainstorm as input for a literature study. This brainstorm is based on inbound logistic cost components that are derived from the cost of goods sold presented by Langley et al. (2009):

- **Ordering cost**: cost related to ordering products at the supplier and is dependent on the individual order size and the number of orders placed per year;
- **Transport cost**: cost incurred by transporting the ordered goods from the supplier to the factory;
- **Handling cost**: cost as a result of the personnel needed to check, unload and store the ordered goods delivered at the factory;
- **Storage cost**: stock maintained in a warehouse requires space and prevents the money spend in inventory to be invested on other things and thus leads to a cost component;
- **Quality cost**: by receiving goods that do not meet the required quality standard, extra cost are incurred for handling, storing and transporting them. The goods and processes are not adding value to the final product because they are not used and are thus a cost component.

Of these five components only four are considered to be leading in the brainstorm sessions and the literature study. The last component of quality cost is of less importance for Danone Baby
Nutrition because currently the transport contracts are DDP, meaning that the cost incurred by
sending products that are not fulfilling the requirement are for the supplier. Thereby is the
number of products that is not meeting the requirements rather small and thus the quality cost
are assessed not to be of great importance.

When considering the transport cost, it is clear that this component can be reduced by decreasing
the number of trips made every year to deliver all products. This simply means that the ordering
size will be increased; thereby improving the trucks utilization, but this also leads to higher storage
costs due to increased inventory levels. So the load factor of the truck has to be increased but
preferably without other side effects. This goal is reached by consolidating shipments of multiple
suppliers. Two concepts have been found by the researcher that enable this principle:

- Milk-run
- Cross-docking

The storage cost component is an important one as well, since this is not a value adding activity
and only serves to accommodate various fluctuations in demand and supply of materials. This
has become clear in the last years and resulted in the trend that companies are striving to reduce
their inventory levels. Again two concepts are found that influence the storage cost:

- Just-in-Time delivery
- Vendor Managed Inventory

The four above mentioned concepts are also influencing the handling and ordering costs. However
these two cost components are assumed to be less important, so therefore no specific concepts are
included that only influence one of these two components.

Besides these four concepts also carrier assignment by the buyer, a concept in which not the
supplier but the buyer chooses the carrier under DDP (Delivered Duty Paid incoterm) thereby
reducing transport cost, and ex-works purchasing (EXW incoterm), where the supplier only sells
the products and the buyer arranges the transportation and carries the risk, are feasible concepts
for Danone Baby Nutrition. But because these concepts are purely based on the current trans­
port market conditions they are not included. The four concepts that are included will now be
described in more detail in the next section.

4.2 Detailed description of inbound logistic concepts

A total of four inbound logistic concepts are used for the inbound logistic decision support model.
Before this model can be developed a better understanding of these concepts is required. This
understanding will be created for each concept in the next four paragraphs that each contain a
detailed description of the concept with its advantages and disadvantages that are either found in
literature of identified by the researcher.

4.2.1 Milk-run

A way of consolidating multiple shipments in a truck is by having a pick-up run in which all orders
are collected; this principle is known as milk-run logistics and is actually a reversed distribution
run. As can be imagined, logistic service providers are the main users of this option. However
multiple car manufacturers in Asia are using the concept as well for the supply of raw materials

1A more detailed explanation of the DDP incoterm and an overview of all incoterms can be found in appendix C.
and components for production (Nemoto et al., 2010). In figure 4.1 the concept is illustrated and compared with the current procedure. In this figure it is assumed that the logistic service provider that performs the milk-run made his last drop near the first supplier in the milk-run and has a new shipment ready for pick-up near the factory.

The main advantage of using a milk-run is the improved load factor of inbound trucks as a result of consolidating of smaller shipments. This leads eventually to a reduction of transport costs (Invovation, 2003; le Blanc et al., 2006; Nemoto et al., 2010 and Potter et al., 2006). According to the researcher part of the transport cost savings can be used to obtain a reduction in inventory by increasing the replenishment frequency, this is also supported by Potter et al. (2006). Other advantages mentioned are a reduction in transport kilometers driven (Invovation, 2003; Nemoto et al., 2010 and Potter et al., 2006), lower dock occupation (Invovation, 2003) and increased supply chain visibility (Potter et al., 2006). The researcher finds it also useful to mention that no sophisticated software packages are required to perform a milk-run, only extra communication with the suppliers on organizational topics such as the arrangement, frequency and pick-up times.

The idea of a milk-run is the consolidation of shipments and thus it is required to have LTL\(^2\) shipments (Invovation, 2003) of multiple suppliers that are preferably located near each other in a cluster (le Blanc et al., 2006). It should be kept in mind that partial loads can also be created by splitting a full truckload (FTL) into multiple LTL shipments by increasing the shipping frequency. When these loads are combined, they should have compatible transport conditions (ambient/chilled/frozen), although there are also trailers on the market that have two compartments with different temperature settings. As a result of the disadvantage on demand variations, it is required that the products included in a milk-run have a stable demand pattern at the buyer to minimize changing routes and extra workload to regenerate these routes every time.

The last requirement is on contract with the supplier. Because in a milk-run the transportation is arranged by the buyer, an ex-works contract (EXW incoterm) should be in place. This means that the buyer only buys the product and as to pick it up at the supplier. However the contract with the supplier can be changed, but the buyer has to be prepared that the supplier is potentially not willing to cooperate.

\(^2\)Less-than-Truckload
Based on the advantages, disadvantages and requirements presented in this paragraph, the overview below can be created. Here it should be noted that especially the advantages are dependent on the specific situation in which the milk-run is applied.

- **Advantages**
  - Reduced transport costs
  - Optional: inventory reduction
  - Reduced transport kilometers driven
  - Lower dock occupation
  - Increased supply chain visibility

- **Disadvantages**
  - Hard to include demand disturbances
  - Transport disturbances affect next suppliers in the route

- **Requirements**
  - Partial loads (LTL)
  - Ex-work contract (EXW)
  - Compatible transport conditions (ambient/chilled/frozen)
  - Stable demand

The milk-run concept is based the idea of consolidating shipment; the concept of cross-docking in the next paragraph is also derived from combining loads.

### 4.2.2 Cross-docking

In a cross-docking arrangement partial loads are send to a cross-dock center (warehouse) to be transshipped with other partial shipments and transported to the factory in one truck. It has to be noted that the products are only temporary stored at this cross-dock center (mostly with a maximum of 12 hours, Kreng and Chen (2008)). In figure 4.2 this concept is visualized to get a better understanding.

![Cross-dock network](image)

**Figure 4.2: Illustration of a cross-dock network compared with the current situation**

As can be imaged, one of the advantages of cross-docking is a reduction of logistic costs due to improved transport efficiency (LTL shipments are combined into full truckloads). This advantage is mentioned in Blanchard (2008), Cook (2007), Kreng and Chen (2008), Logistiek (n.d.), Vogt (2010) and Yang et al. (2010). Besides the cost reduction mentioned in these sources, they also all mention a possible stock reduction by sending smaller shipments more frequently. Galbreth et al. (2008) also presents this advantage. From the perspective of the researcher another advantage can be addressed here, because multiple smaller shipments are combined in one shipment the number of trucks that have to unload goods at the destination, in this case the factory, will be reduced and therefore the dock occupation is decreased under the condition that the delivery frequency remains the same. Another advantage over a milk-run is that the contract terms with the supplier
can remain the same do not need to change; only the delivery location has to be changed from the factory to the cross-dock facility. This is especially useful with suppliers that are unwilling to change the contract terms.

However, using a cross-docking arrangement also has some disadvantages. First of all, the lead time will be longer since the products have to be transshipped and are not directly transported from the supplier to the customer as mentioned by Supply Chain Digest (2011). An additional disadvantage according to the researcher is the need to synchronize the orders and deliveries of the products in a cross-docking configuration. This increases the workload and eventually also the labour costs.

Cross-docking is not suitable for all types of products. The most mentioned requirement is a stable demand of the product with a high yearly volume (Li et al., 2008; Supply Chain Digest, 2011; Gross & Associates, n.d.; Ertek, n.d., Vogt, 2010) since inventory is serving little purpose in this case. According to Ertek (n.d.) and Vogt (2010) high cooperation and coordination is required to make cross-docking work. Vogt (2010) even states that the suppliers have to be reliable and efficient for cross-docking because they always have to deliver the full quantity of products ordered on time. According to Vogt (2010) it is also required that the shipments that are combined at the cross-dock center have the same handling/transportation requirements or that they can at least be combined in the same semi-trailer so for example the same transport temperature (ambient/chilled/frozen). This is only a minor requirement since there are semi-trailers available with two compartments and only palletized goods are in scope for this research as was mentioned in chapter 2. Because cross-docking is effective due to the combination of LTLs into one FTL, the shipments have to be less than truckload shipments of course. This all together leads to this next overview:

**Advantages**
- Reduced logistic costs
- Possible inventory reduction
- Lower dock occupation
- No need to change the contract

**Disadvantages**
- Longer lead time
- Need to synchronize orders

With this list, the concept of cross-docking has been completely explained and the step to another option, Just-in-Time delivery, can be made.

### 4.2.3 Just-in-Time delivery

The concept of Just-in-Time delivery finds its origin in the Toyota Production System (Spear and Bowen, 1999). When using this concept in production, all required components are provided at the machine at the time that they are required thereby eliminating waiting time that is seen as waste. This philosophy can be expended upstream to the delivery of goods at the factory which happens just before the goods are needed for production, Just-in-Time delivery.

As can be imagined there is no inventory needed in the ideal situation since all components required for production are delivered at the moment they are needed. In the end a zero inventory situation is hard to achieve, but the advantage of inventory minimization remains and this is by
However a change in total cost will not give insight in the real effects of a concept, so therefore four different cost components are identified by using Supply Chain Council (2010) and Langley et al. (2009):

1. Transport cost
2. Inventory cost
3. Ordering cost
4. Handling cost

The transport and ordering costs are rather straightforward and related to the price paid for the transportation from the supplier’s location to the buyer and the cost of issuing an order. The inventory costs mentioned here, are the cost related to holding the inventory and will consist of two components. The first component is the cost of physical storage and the second one is the cost of capital per item. The handling cost will contain the cost of handling the inbound goods until they are stored in the warehouse. These four components will be used to explain the effect of a concept on the total cost and to give more insight in which cost components are be reduced or increased and what their relative share is in the total costs so that the important components are identified.

Thus the model will contain four cost components leading to the overall total inbound logistic cost that is used to determine the performance of a concept in a specific situation. However the problem owner of this research, Danone Baby Nutrition, is also paying a lot of attention to the invested amount of capital, which is in this case mostly in inventory, and therefore this will also be included as a criterion besides the one on total cost reduction. With invested capital is meant that this is the amount of money that is invested in materials and thereby not available for other investments. However when these materials are sold again, this capital will be accessible to use for other investments.

So in the end, the concept performance assessment is based on the criteria of total cost and invested capital. However when looking at selecting only the best one from a company’s point of view, it can be stated that when one option is presented as the solution there is a problem. When two options are presented this will lead to a dilemma, while three options offer a choice. So instead of letting the model present only one option, a ranking of all included concepts will be the output of the model. This is what makes it a decision support model and not a decision model. Before this output can be created a number of steps have to be taken first. These steps will be presented in the next section by use of a flowchart and a matching description.

### 5.2 Flowchart of the inbound logistic decision support model: Steps and processes

In the previous section it became clear that the output of the logistic decision support model will be a ranking of the included concepts in specific situations based on their effect on the total inbound logistic costs and invested capital. Between the identification of the possible concepts in the previous chapter and the ability to present a ranking of the concepts by using the inbound logistic model, a number of steps have to be taken. These steps will all be explained based on the flowchart of the decision support model illustrated in figure 5.1 on the next page. In this figure the red boxes indicate the steps that have to be performed to generate the input, the blue ones are the performance assessment models and the green boxes are the output of the decision support model. This structure of input, calculation models and output will be used to describe them in more detail.
5.2.1 Input

The input of the inbound logistic decision support model is a result of combining the supplier portfolio of a factory and the concept requirements that have to be fulfilled. Combining these two components leads to a number of so-called supplier-concept-combinations (SCC’s). These SCC’s are unique situations in which one or more suppliers are related to one of the four logistic concepts. The complete process up to the identification of possible supplier-concept-combinations will be extensively described in chapter 9. This will be done after the development of the calculation models because these models give better insight in the important parameters and offers a quantitative approach instead of the qualitative requirements presented in chapter 4.

So the input for the performance assessment models is created by the data of a number of supplier-concept-combinations that are unique for a factory. These performance assessment models will be discussed now.

5.2.2 Performance assessment models

As mentioned before, the four concepts will be evaluated based on their effect on the amount of invested capital and the total cost, consisting of transport, inventory, handling and ordering costs. For each of these five components an individual (partial) model will be developed. These general models will be included in the concept performance assessment models in order to guarantee the comparability of the results. So each concept performance model will contain these five general calculation models. However when it is required the general models are adapted to better fit the specific concept. First of all the general calculation models are developed in the next chapter (chapter 6), after which the concept performance assessment models are developed in chapter 7.
Thus the concept performance models are based on the general calculation models and obtain their input from the supplier-concept-combinations. Because it is likely that there are multiple SCC's based on one concept but with different suppliers it is chosen by the researcher to include up to three different situations per concept. In practice the decision support model can be expanded to include as much situations per concept as needed. But the researcher assumed that for the first application of the model three situations per concept should be sufficient. So a total of 12 unique SCC's can be included in the constructed model. Based on the input of these 12 SCC's the performance will be calculated with the concept performance assessment models, resulting in the effect of each SCC on the five different criteria.

5.2.3 Output

The output of the concept calculation models will be on their effect on:

- Total cost:
  - Transport cost
  - Inventory cost
  - Handling cost
  - Ordering cost
- Invested capital

The main selection criteria that will be used by the decision support model are the total inbound logistic costs and the invested capital, so the output of the concept models has to be merged in order to get the total costs. In the end all the output of all 12 SCC's that can be included have to be combined in a ranking, since it was decided that recommending only the best SCC is limiting the options for the model user.

The ranking can be either based on the absolute change between the current and future situation or on the effectiveness of a concept or SCC, which is defined by the relative change between the current and future situation. From a business perspective the absolute change is most relevant, so therefore the ranking will be done based on this absolute change. At first instance this will be done on the total cost; however an option will be included to rank the SCC on their effect on capital as well.

The three individual parts of the inbound logistic decision support model have been introduced and explained on a high-level. In the following chapters the decision support model will be discussed in more detail, starting with the general concepts models that are then included in the development of the concept performance assessment models. With these models the complete decision support model can then be constructed. When this is all done, the process of identifying SCC's and how to tackle the complexity in this process will be described after which the complete model is applied in a case study.
Chapter 6

General calculation models

The first step in constructing the inbound logistics decision support model is made here by developing and presenting general calculation models that can be used for the concept performance models as modular blocks. These general calculation models will quantify results with respect to the criteria mentioned in chapter 5: (1) transportation costs, (2) inventory costs, (3) handling costs, (4) ordering costs and (5) invested capital. The first four criteria are based on cost components found in Supply Chain Council (2010) and Langley et al. (2009). The last criterion is included because Danone Baby Nutrition always uses this in their decision making process. So for each of these five criteria an individual model is being developed.

The five general models are considered to be building blocks for the concept performance models and justify the comparison of various concepts because the calculation methods per criterion are the same for every concept. The first general component that will be introduced is the transport cost model.

6.1 Transport cost model

The first general calculation model that will be described is the one that calculates the costs for road transport. In practice this is often done by using a rule-of-thumb, in which the total transportation costs between two locations is determined by multiplying the distance with a fixed price per kilometer. The resulting price for a trip is often used in business cases that estimate the effect of a measure. However this method is considered to be not accurate enough according to the researcher, so therefore the transport cost model of van der Vlist (2007) is used as a starting point for further development:

\[ C_{\text{transport}} = P_{\text{km}}(d_{ij} + e) + n_{\text{stops}} \cdot P_{\text{docking}} \]  

With the following properties (van der Vlist, 2007):

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_{\text{transport}} )</td>
<td>Total yearly transport cost</td>
<td>€</td>
</tr>
<tr>
<td>( d_{ij} )</td>
<td>Distance by road between point A and B</td>
<td>km</td>
</tr>
<tr>
<td>( e )</td>
<td>Empty kilometers after unloading</td>
<td>km</td>
</tr>
<tr>
<td>( n_{\text{stops}} )</td>
<td>Number of stops in a route</td>
<td>-</td>
</tr>
<tr>
<td>( P_{\text{docking}} )</td>
<td>Cost for docking a truck</td>
<td>€</td>
</tr>
<tr>
<td>( P_{\text{km}} )</td>
<td>Transport price per kilometer</td>
<td>€/km</td>
</tr>
</tbody>
</table>
The equation can be used to calculate the transport cost of one trip between point A and point B. To determine the annual transport cost for a lane between these two points, the formula has to be multiplied by the number of trips performed on a yearly basis. When this is done, it results in the following equation:

\[ C_{\text{transport}} = (p_{km}(d_{ij} + e) + n_{\text{stops}} \cdot p_{\text{docking}}) \cdot n_{\text{trip}} \]  

(6.2)

In which \( n_{\text{trip}} \) is the number of trips performed per year on a lane. The mentioned formula is a linear equation in which no distinction is made between full truckloads (FTL) and less than truck loads (LTL, also called partial loads). In practice the transport cost per pallet is lower when full truckloads are being shipped. This difference is caused by the fact that the logistic service providers have to pick-up at least one other load to increase/maximise the utilization of the truck in case of partial loads. This difference has to be included in the transport cost equation as well. When taking a closer look at this transport cost equation, some components are independent of the number of pallets shipped. This is first of all the cost for docking a truck, this component will remain equal to \( n_{\text{stops}} \cdot p_{\text{docking}} \). When the load is delivered at its destination, whether this is a full truckload or a partial load, the logistic service provider has to drive to another customer to pick-up another (return) load. So the only remaining component that can be distributed over the number of pallets, is the transport cost related to the distance. When this is done and the distance to the next customer to maximize the utilization is included, this leads to:

\[ C_{\text{transport}} = \left( p_{km} \cdot \frac{v}{v_{\text{truck}}} \cdot d_{ij} + p_{km} \cdot e + n_{\text{stops}} \cdot p_{\text{docking}} + p_{km} \cdot e \cdot L \right) \cdot n_{\text{trip}} \]

(6.3)

With \( L = \begin{cases} 1 & \text{if shipment is LTL;} \\ 0 & \text{if shipment is FTL.} \end{cases} \)

In this equation \( v \) is the volume shipped in pallets and \( v_{\text{truck}} \) is the maximum number of pallets that fit in a truck. In practice a full truckload is not always equal to the maximum amount of pallets that fits in a trailer. When 33 euro pallets fit in a standard 13.6m trailer, a full truckload can for example be all shipments that contain at least 28 euro pallets (85%). For so for shipments with 28 pallets or more the transport price is equal to the one of a full truckload. This has to be incorporated in the presented transport cost equation as well because now there is a gap. This gap is caused by the fact that equation 6.3 is only equal to formula 6.2 when 33 pallets are shipped. This can be solved by replacing \( v_{\text{truck}} \) with \( v_{\text{FTL}} \), the minimum volume of a full truckload. When this is done, it leads to:

\[ C_{\text{transport}} = \left( p_{km} \left[ \frac{v}{v_{\text{FTL}}} \right] \cdot d_{ij} + (1 + L)e \right) + n_{\text{stops}} \cdot p_{\text{docking}} \cdot n_{\text{trip}} \]

(6.4)

With \( L = \begin{cases} 1 & \text{if shipment is LTL (< }v_{\text{FTL}}); \\ 0 & \text{if shipment is FTL (} \geq v_{\text{FTL}}). \end{cases} \)

As a result of the fact that \( v/v_{\text{FTL}} \) can be greater than one, the minimum of either \( v/v_{\text{FTL}} \) or 1 has to be taken. This is included by stating \( \left[ v/v_{\text{FTL}}, 1 \right] \), which is equal to \( \min(v/v_{\text{FTL}}, 1) \). The presented model does not include any form of quantity discount which is applied in practice on the distance, shipment size and yearly number of shipments. This will cause a gap between actual transport prices and the prices predicted by this model. So this should be kept in mind when using this model.

When the distance has to be determined for only a limited number of routes, this can be done by using a route planner on the internet that gives the exact distance. However when considering
large networks this will be an enormous job to manually determine the distances between all nodes in this network. When for example 10 suppliers are present in a network in total 90 links between 2 suppliers exist. Despite the fact that this can be reduced to 45 links when assuming that the distance is equal in both directions ($d_{ab} = d_{ba}$, symmetric distance matrix), it still results in a lot of work. So to reduce the workload of finding this distance, grid coordinates can be used to calculate the distances between two locations with the following equation:

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$  \hspace{1cm} (6.5)

This equation presents the direct distance between two locations in grid coordinates and can thus not be used to calculate the transport costs between these locations. To solve this problem, two conversion factors are added:

- Detour factor $f_d$: This factor converts the direct distance to an approximate driving distance;
- Distance factor $f_u$: This factor corrects for the fact that the coordinates are not in kilometers.

Leading to the following equation to determine the distance between two locations:

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \cdot f_d \cdot f_u$$  \hspace{1cm} (6.6)

Using this equation with grid coordinates to state the supplier’s location, will later on especially be useful when it is needed to determine the optimal facility location in a cross-dock situation. Using grid coordinates will lead to a minimal difference with the reality because the curvature of the planet is neglected. This is taken for granted because it is assumed that this deviation is limited when applying this equation for links within the European Union.

Every aspect of the transport cost model has been presented so that now the next general model on inventory costs can be introduced.

### 6.2 Inventory holding cost model

Inventory is amongst others used to accommodate fluctuations in supply and last minute changes in a production schedule. Inventory also makes it possible that there are a finite number of trucks needed to supply all materials required for production at a factory. But there exists a trade-off between the number of shipment needed and the inventory levels. Since the 2008 financial crisis, inventory levels have been a hot topic, resulting in companies that are striving to reduce the inventory levels. Danone Baby Nutrition is one of these companies. In order to assess the impact on inventory levels and related costs, this paragraph presents an inventory cost model.

Before this model is developed, it is necessary to understand where inventory is used for by companies. According to Reid and Sanders (2007), companies use their inventory in the following six ways:

1. **Anticipation inventory or seasonal inventory;**
   - This inventory is used to anticipate on future demand, planned promotions, seasonal fluctuations, plant shutdowns and holidays.
2. **Fluctuation inventory/safety stock;**
   - Stock kept to protect against possible demand variations or unexpected demand.
3. **Lot-size inventory/cycle stock;**
   - This is held when a company buys more than immediately needed and is thus done at all manufacturing companies since it hard to obtain all materials exactly at the time needed.
4. Transportation/pipeline inventory;
   - Inventory in transit between the supplier and the manufacturing plant.

5. Speculative/hedge inventory;
   - This is inventory that is build-up to protect against unexpected situations in the future such as price increase, a strike at the supplier or scarcity of a product.

6. Maintenance, repair and operating (MRO) inventory;
   - This type of stock includes all components (except materials used for production) needed to keep the production system running, examples are spare parts, lubricants, cleaning materials and so on.

Two out of the six mentioned types of inventory are mostly considered when looking at inventory: (1) safety stock and (2) cycle stock. However, transportation/pipeline inventory is interesting as well to include in this model because when a concept requires a different incoterm, this influences the ownership of the products shipped and thus the total inventory held. For this type of inventory, the transportation cost can be seen as a general cost component that includes also a holding costs component. So therefore this type of inventory is excluded here but later on included in the capital model. Since the focus of this research is on the normal flow from suppliers to the factory, the other three types of inventory will not be included in this analysis. These three types are considered to be special cases.

Before the cycle stock and safety stock model are presented, it should first be noted that the inventory cost consists of two different elements:

- **Cost of physical storage an item**: this component represents the cost related to storing the product in a warehouse;

- **Cost of capital per item** is the interest rate the company has to pay to borrow the money to invest in inventory (Reid and Sanders, 2007).

So all of the presented inventory models will both include the cost of physical storage and cost of capital, of which now first the cycle stock model is introduced.

### 6.2.1 Cycle stock model

Cycle stock is used for production and is ideally replenished on the same moment as the last item on stock was used for production. When assuming this "just-in-time" delivery combined with a constant and known demand, the following figure of the cycle stock level can be made:

![Figure 6.1: Traditional saw-tooth inventory pattern](image-url)
As can be seen this figure presents a saw-tooth pattern of which the average stock level is half of the replenishment quantity $Q$. This replenishment quantity is constant as a result of the constant and known demand. A standard equation to calculate the annual cycle stock costs is (van der Vlist, 2007; Langley et al., 2009):

$$C_{cycle} = \frac{Q}{2} \cdot H = \frac{Q}{2} \cdot \bar{v}_{pallet} \cdot P_{carrying}$$  \hspace{1cm} (6.7)

Realize that this only includes the cost of capital and therefore the cost of physical storage $p_{store}$ has to be included as well:

$$C_{cycle} = \frac{Q}{2} \cdot (H + p_{store}) = \frac{Q}{2} \cdot (\bar{v}_{pallet} \cdot P_{carrying} + p_{store})$$  \hspace{1cm} (6.8)

The units in this equation are normally undefined and stated per "unit", at this point it is chosen by the researcher to apply this equation on pallet level for Danone Baby Nutrition, leading to the following symbol descriptions:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{cycle}$</td>
<td>Annual holding cost for cycle stock of a supplier</td>
<td>€</td>
</tr>
<tr>
<td>$H$</td>
<td>Annual holding cost per unit</td>
<td>€/pallet</td>
</tr>
<tr>
<td>$P_{carrying}$</td>
<td>Carrying cost per euro of inventory per year</td>
<td>% of pallet value</td>
</tr>
<tr>
<td>$p_{store}$</td>
<td>Cost of physical storage per pallet location per year</td>
<td>€/pallet/year</td>
</tr>
<tr>
<td>$Q$</td>
<td>Quantity ordered</td>
<td>Pallet</td>
</tr>
<tr>
<td>$\bar{v}_{pallet}$</td>
<td>Average pallet value</td>
<td>€/pallet</td>
</tr>
</tbody>
</table>

Danone Baby Nutrition is operating in the food industry where high quality standards are used. This leads to high requirements on supplied raw materials and packaging. Extra lead time is present due to a quality control that has to be performed before the materials can be used. Despite the fact that the duration of this quality control varies, it leads to the general pattern of individual replenishment actions displayed in figure 6.2. In this figure the individual replenishment inventory levels (figure 6.2a) are displayed together with the total inventory level (see figure 6.2b). In this case the overlap is equal to the duration of the quality control leading to an elevated saw-tooth pattern.

![Diagram](image)

(a) Individual replenishment inventory levels  \hspace{1cm} (b) Total inventory level

Figure 6.2: Inventory levels when quality control is required.

This quality check also influences the holding cost of the cycle stock and it should therefore be included in the equation to calculate the annual holding costs. Normally this is not included as could be seen in equation 6.7.
In appendix D the equation is derived that calculates the average inventory level including quality control and overlapping replenishment actions. This leads to the next formula:

\[ I_{cycle} = \frac{Q \cdot [t_{qc}, t_o] + \frac{Q}{2} t_p}{t_p + [0, t_{qc} - t_o]} \]  

(6.9)

With:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q)</td>
<td>Quantity ordered</td>
<td>Pallet</td>
</tr>
<tr>
<td>(t_o)</td>
<td>Overlapping time of replenishment actions</td>
<td>Day</td>
</tr>
<tr>
<td>(t_p)</td>
<td>Production time per delivered quantity</td>
<td>Day</td>
</tr>
<tr>
<td>(t_{qc})</td>
<td>Quality control duration</td>
<td>Day</td>
</tr>
</tbody>
</table>

The symbols used in this equation are visualized in figure 6.3 on the next page for a situation with overlapping replenishment actions. The overlap of replenishment actions is necessary to guarantee a constant feed of materials to the production process because a quality control has to be performed before the materials can be used.

![Figure 6.3: Symbols for replenishment actions with overlap and quality control](image)

Adapting the standard cycle stock cost equation (equation 6.7) with the average inventory equation (equation 6.9) leads to the following equation for the inventory costs related to the cycle stock:

\[ C_{cycle} = \frac{Q \cdot [t_{qc}, t_o] + \frac{Q}{2} t_p}{t_p + [0, t_{qc} - t_o]} \cdot (p_{pallet \cdot p\text{carrying} + p\text{store}}) \]  

(6.10)

This equation has to be adapted to one other aspect as well. In chapter 3 the principle of Repetitive Flexible Supply was already introduced. Shortly this principle means that the production schedule is fixed for a set period with a constant repeating pattern. As a result of this principle there is a probability that products are only kept in stock during the period in which they are needed for production. This would lead to a different pattern of the inventory level as presented in figure 6.4 on the next page, which both includes overlap and idle time between production cycles.
To capture this effect, the utilization $U$ of a certain material has to be known. This utilization is calculated by:

$$U = \frac{\text{Number of days per year required for production}}{365} = \frac{\sum t_{p,i}}{365} \quad (6.11)$$

This equation is based on 365 production days per year. In practice this will be lower as a result of maintenance, start-up time and activities during which there is no production. So the 365 days have to be changed when the actual uptime of the production site is known. In the end it leads to the following equation for the calculation of the cycle stock cost:

$$C_{cycle} = U \cdot \frac{Q \cdot [t_{qc}, t_o] + Q \cdot t_p}{t_p + [0, t_{qc} - t_o]} \cdot (\bar{v}_{pallet} \cdot p_{carrying} + p_{store}) \quad (6.12)$$

For which:

$$\bar{I} = U \cdot \frac{Q \cdot [t_{qc}, t_o] + Q \cdot t_p}{t_p + [0, t_{qc} - t_o]} \quad (6.13)$$

The researcher realizes that there is a potential bias between the real average and the calculated average due the effect of the first and the last replenishment action on the total inventory level. The cause of this bias is highlighted in figure 6.5 on the next page.

The size of the bias is dependent on the number of replenishment cycles within one production cycle. This bias should be kept in mind when applying the inventory cost model, however the accuracy is already far better compared to the standard formula used (equation 6.7) and therefore this bias is accepted. So an equation is established to determine the inventory costs related to the cycle stock, now the next step can be made to the safety stock model in the next paragraph.
6.2.2 Safety stock model

Safety stock is used to capture possible fluctuations of any kind. In scientific literature the size of this safety stock is dependent on the demand variation during the lead time. This can be seen in the next equation from Reid and Sanders (2007) and will be applied here on pallet level which is in line with the cycle stock equation:

\[ SS = z \cdot \sigma_{dL} \]  

(6.14)

With:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>Safety stock level</td>
<td>Pallet</td>
</tr>
<tr>
<td>z</td>
<td>Number of standard deviations</td>
<td>-</td>
</tr>
<tr>
<td>( \sigma_{dL} )</td>
<td>Standard deviation of demand during the lead time</td>
<td>Pallet</td>
</tr>
</tbody>
</table>

Besides the variation in demand during the lead time, there will also be a variation in the lead time itself which will be caused by the product availability at the supplier and transport conditions such as weather and congestion. As can be imagined, during the winter snow can lead to significant longer transport times.

Besides the theoretical statement used in literature to calculate the safety stock levels and associated costs, there are also other factors of the day to day operations of a factory that are influencing the safety stock levels. Examples are the perishability of unfinished goods and variations in the demand of unfinished goods. The latter one can be explained by unexpected production runs leading to a deviation in the normal demand pattern.

After all there is no clear equation available that incorporates all these variables that are influencing the safety stock levels. Therefore the researcher made the decision that the safety stock model will not be included in the inbound logistic decision support model.

Total inventory holding cost

Since the safety stock is be included in the rest of the model construction, the total inventory level will only be dependent on the cycle stock. This leads to the following equation:

\[ C_{\text{inventory}} = C_{\text{cycle}} = U \cdot \frac{Q \cdot [0, t_{qc}, t_o] + Q(t_p)}{t_p + [0, t_{qc} - t_o]} \cdot (\bar{v}_{pallet} \cdot p_{\text{carrying}} + p_{\text{store}}) \]  

(6.15)
6.3 Handling cost model

When a truck with goods from a supplier arrives at the factory, it has to be unloaded. In case of Danone Baby Nutrition this is done by their employees. The costs involved with this unloading process are caused by the salary of these employees. In literature, such as van der Vlist (2007), a constant and fixed value per pallet is used to determine the handling costs with the following values:

- Unloading, receipt and storage: €4 per pallet;
- Unloading, cross dock and loading (= transfer): €3 per pallet.

In this case, it would mean that the handling costs are independent on the number of trucks that is used to fulfil the annual demand. Thereby it is considered to be insufficient to use a constant and fixed value for the receiving company, so therefore a new model will be developed for the situation of unloading a truck at the factory. The transfer costs are assumed to be constant since this is a process that is outsourced most of the times.

So when considering the inbound process at Danone Baby Nutrition (see figure 3.6), a number of different steps can be identified within the process "Unloading" that are considered for developing a more detailed handling cost model:

1. Check the truck and transport documents;
2. Unload, check and label incoming pallets;
3. Store pallets.

The first of these three components is dependent on the number of trucks that arrive, whereas the other two are related to the number of pallets that arrive on a yearly basis. So therefore an equation is developed to calculate the yearly handling costs based on these two parts:

\[
C_{\text{handling}} = n_{\text{trucks}} \cdot t_{\text{check}} \cdot S_h + n_{\text{pallets}} \cdot t_{\text{unload}} \cdot S_h
\]

With:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_{\text{handling}} )</td>
<td>Total yearly handling cost</td>
<td>€</td>
</tr>
<tr>
<td>( n_{\text{trucks}} )</td>
<td>Number of trucks that arrive per year</td>
<td>-</td>
</tr>
<tr>
<td>( n_{\text{pallets}} )</td>
<td>Number of pallets that arrive per year</td>
<td>-</td>
</tr>
<tr>
<td>( S_h )</td>
<td>Hourly salary of an inbound warehouse employee</td>
<td>€/hr</td>
</tr>
<tr>
<td>( t_{\text{check}} )</td>
<td>Time required to check the truck and transport documents</td>
<td>Minute</td>
</tr>
<tr>
<td>( t_{\text{unload}} )</td>
<td>Time required to unload, check, label and store incoming pallets</td>
<td>Minute</td>
</tr>
</tbody>
</table>

Using this equation makes it possible to identify cost savings in handling costs when larger quantities are being shipped, resulting in less trucks per year. However, before this equation can be applied, values have to be determined for \( t_{\text{check}}, t_{\text{unload}} \) and \( S_h \). The other input parameters \( n_{\text{trucks}} \) and \( n_{\text{pallets}} \) are supplier specific and will thus be intermediate output in the concept models.

6.4 Ordering cost model

All costs combined of placing an order are called "ordering costs" and includes activities as checking the inventory levels and the production schedules to determine the order-quantity and also the actual order placement by a buyer. It is chosen to keep this model simple and straight forward
by using a fixed cost component for placing one order. With this fixed cost per order, the next equation is used to determine the annual ordering costs incurred by a factory for a certain supplier:

\[ C_{order} = n_{order} \cdot P_{order} \]  

(6.17)

With:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(C_{order})</td>
<td>Total yearly ordering costs</td>
<td>€</td>
</tr>
<tr>
<td>(n_{order})</td>
<td>Number of orders placed per year</td>
<td>-</td>
</tr>
<tr>
<td>(P_{order})</td>
<td>Ordering cost per order</td>
<td>€/order</td>
</tr>
</tbody>
</table>

With the ordering cost model, almost all general calculation models have been presented. The last one that will be introduced is the capital model in the next paragraph.

### 6.5 Invested capital model

The previous models were related to costs in a sense that after spending the money, it was unable to get it back. When considering the capital that is invested in inventory, this is a different case, because when this inventory is sold again, the invested money will be available again. As was already mentioned in the previous chapter, Danone Baby Nutrition is paying rather great importance to the amount of capital that is invested in inventory. Therefore a separate model will be presented here that calculates this amount.

It can be rather confusing that this is considered as a different component since there is also a cost of capital component in the inventory cost model. That is why the difference will be explained first by stating the definitions used here for inventory costs and for invested capital:

- Inventory costs are the costs incurred by holding the inventory and consists of the physical storage of the inventory in a warehouse and the interest rate paid to borrow the money invested in inventory;
- Invested capital is the money invested in inventory by purchasing this inventory, the difference with inventory costs is that the investment of capital can be made undone.

Now that the difference between inventory costs and invested capital is clear, the model can be presented that includes two components. This is in line with the components included in the inventory costs model:

- Cycle stock capital model
- Transportation inventory capital model

For the cycle stock model some equations will be used that were already presented in the related cost models. In general, the amount of invested capital in inventory can be calculated as follows according to the researcher:

\[ G = \bar{I} \cdot \bar{v}_{pallet} \]  

(6.18)

With:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(G)</td>
<td>Amount of invested capital</td>
<td>€</td>
</tr>
<tr>
<td>(\bar{I})</td>
<td>Average inventory level</td>
<td>Pallet</td>
</tr>
<tr>
<td>(\bar{v}_{pallet})</td>
<td>Average pallet value</td>
<td>€/pallet</td>
</tr>
</tbody>
</table>

This equation will now first be applied for the cycle stock capital model.
6.5.1 Cycle stock capital model

The cycle stock, as mentioned before, is used to supply the production process. When the cycle stock cost model was introduced, the following equation was used to calculate the average stock level of supplier $i$:

$$I_{cycle,i} = U \cdot \frac{Q \cdot [t_{qc}, t_o] + Q \cdot \frac{2}{2} t_p}{t_p + [0, t_{qc} - t_o]}$$  \hspace{1cm} (6.19)

When this equation is combined with formula 6.18 it results in:

$$G_{cycle,i} = I_{cycle,i} \cdot \bar{v} = \left( U \cdot \frac{Q \cdot [t_{qc}, t_o] + Q \cdot \frac{2}{2} t_p}{t_p + [0, t_{qc} - t_o]} \right) \cdot \bar{v}_{pallet,i}$$  \hspace{1cm} (6.20)

6.5.2 Transportation/pipeline inventory capital model

The second and last inventory capital model is related to the inventory owned by Danone while it is still in transit. This specific situation is only valid when the products are ordered under the condition that the goods are paid when they are picked up at the supplier (incoterm Ex-works, EXW). Despite the fact that this is currently only the case in a few situations, this might change in the future situation with for example milk-runs and cross-docking. Therefore it will be shortly introduced.

When considering transportation or pipeline inventory, there is no storage cost related to this inventory besides the transportation costs paid to move the goods from the supplier to the factory. However, inventory in transit is influencing the amount of capital located in inventory that is being transported.

The average inventory that is in transit can be determined by using the following formula from Reid and Sanders (2007):

$$I_{transit} = \frac{t_{transit} \cdot D}{365}$$  \hspace{1cm} (6.21)

With:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D$</td>
<td>Annual demand</td>
<td>Pallet</td>
</tr>
<tr>
<td>$I_{transit}$</td>
<td>Average level of inventory in transit</td>
<td>Pallet</td>
</tr>
<tr>
<td>$t_{transit}$</td>
<td>Transit time</td>
<td>Day</td>
</tr>
</tbody>
</table>

To assess the amount of money invested in inventory that is being transported and therefore not available for usage, the average inventory level should by multiplied with the average pallet value, leading to:

$$G_{transit} = \frac{t_{transit} \cdot D}{365} \cdot \bar{v}_{pallet}$$  \hspace{1cm} (6.22)

6.5.3 Total invested capital

Both components of the capital model have been presented. Combining these components will lead to the total invested capital model.

$$G = G_{cycle} + G_{transit}$$  \hspace{1cm} (6.23)

$$G = (I_{cycle} + I_{transit}) \cdot \bar{v} = \left( U \cdot \frac{Q \cdot [t_{qc}, t_o] + Q \cdot \frac{2}{2} t_p}{t_p + [0, t_{qc} - t_o]} + I_{safety} + \frac{t_{transit}}{365} \cdot D \right) \cdot \bar{v}_{pallet}$$  \hspace{1cm} (6.24)
6.6 Overview of the general calculation models

In this chapter a total of five different calculation models have been presented to determine the transport cost, inventory costs, handling costs, ordering costs and invested capital. The last section of this chapter gives an overview of all models presented. This is done by first presenting all equations after which a table is included with all symbols that have been used and their description.

- **Transport cost model**
  - This model calculates the transport costs between location $i$ and $j$, in which a distinction is made between full truckloads and partial loads and also includes the number of stops and trips per year:

  \[
  C_{\text{transport}} = \left( pkm \left[ \frac{v}{v_{\text{FTL}}}, 1 \right] \cdot d_{ij} + (1 + L)e \right) + n_{\text{stops}} \cdot p_{\text{docking}} \cdot n_{\text{trip}} \tag{6.25}
  \]

  With $L = \begin{cases} 
  1 & \text{if shipment is LTL} (< v_{\text{FTL}}); \\
  0 & \text{if shipment is FTL} (\geq v_{\text{FTL}}).
  \end{cases}$

- **Inventory cost model**
  - The inventory cost model contains both the cost of physical storage and the cost of capital as a result of the interest rate that has to be paid over the money used to purchase the inventory:

  \[
  C_{\text{inventory}} = C_{\text{cycle}} = U \cdot \frac{Q \cdot [t_{\text{QC}}, t_0] + \frac{Q}{2} t_p}{t_p + [0, t_{\text{QC}} - t_0]} \cdot (\bar{v}_{\text{pallet}} \cdot p_{\text{carrying}} + p_{\text{store}}) \tag{6.26}
  \]

- **Handling cost model**
  - In the process of unloading a shipment, two different processes where identified: (1) Check the truck and documents and (2) unloading and storing the pallets. This led to the following equation:

  \[
  C_{\text{handling}} = \frac{n_{\text{trucks}} \cdot t_{\text{check}}}{60} \cdot S_h + \frac{n_{\text{pallets}} \cdot t_{\text{unload}}}{60} \cdot S_h \tag{6.27}
  \]

- **Ordering cost model**
  - The ordering cost model is kept simple by stating a fixed price per order placed:

  \[
  C_{\text{order}} = n_{\text{order}} \cdot p_{\text{order}} \tag{6.28}
  \]

- **Invested capital model**
  - Invested capital is invested in inventory that is can be located either at the factory or in transit to the factory, thereby leading to:

  \[
  G = (\bar{T}_{\text{cycle}} + \bar{T}_{\text{transit}}) \cdot \bar{v} = \left( U \cdot \frac{Q \cdot [t_{\text{QC}}, t_0] + \frac{Q}{2} t_p}{t_p + [0, t_{\text{QC}} - t_0]} + \frac{t_{\text{transit}}}{365} \cdot D \right) \cdot \bar{v}_{\text{pallet}, i} \tag{6.29}
  \]

For all five models a sensitivity analysis will be performed to determine the important parameters of each equation and also to determine the importance of the four cost components in the total cost.
Table 6.1: Symbols used for the general calculation models

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{handling}$</td>
<td>Total yearly handling cost</td>
<td>€</td>
</tr>
<tr>
<td>$C_{inventory}$</td>
<td>Total yearly inventory cost</td>
<td>€</td>
</tr>
<tr>
<td>$C_{order}$</td>
<td>Total yearly ordering cost</td>
<td>€</td>
</tr>
<tr>
<td>$C_{transport}$</td>
<td>Total transport cost per lane</td>
<td>€</td>
</tr>
<tr>
<td>$D$</td>
<td>Annual demand</td>
<td>Pallet</td>
</tr>
<tr>
<td>$d_{ij}$</td>
<td>Distance between point A and point B</td>
<td>Km</td>
</tr>
<tr>
<td>$e$</td>
<td>Empty kilometers after unloading</td>
<td>Km</td>
</tr>
<tr>
<td>$G$</td>
<td>Amount of cash</td>
<td>€</td>
</tr>
<tr>
<td>$n_{order}$</td>
<td>Number of orders placed per year</td>
<td>-</td>
</tr>
<tr>
<td>$n_{pallets}$</td>
<td>Number of pallets that arrive per year</td>
<td>Pallet</td>
</tr>
<tr>
<td>$n_{stops}$</td>
<td>Number of stops in a route</td>
<td>-</td>
</tr>
<tr>
<td>$n_{trip}$</td>
<td>Number of trips performed on a lane per year</td>
<td>-</td>
</tr>
<tr>
<td>$n_{trucks}$</td>
<td>Number of trucks that arrive per year</td>
<td>Truck</td>
</tr>
<tr>
<td>$p_{carrying}$</td>
<td>Carrying cost per euro of inventory per year</td>
<td>% of pallet value</td>
</tr>
<tr>
<td>$p_{docking}$</td>
<td>Cost for docking a truck</td>
<td>€</td>
</tr>
<tr>
<td>$p_{km}$</td>
<td>Transportation price per km</td>
<td>€/km</td>
</tr>
<tr>
<td>$p_{order}$</td>
<td>Ordering cost per order</td>
<td>€/order</td>
</tr>
<tr>
<td>$p_{store}$</td>
<td>Cost of physical storage per pallet location per year</td>
<td>€/pallet/year</td>
</tr>
<tr>
<td>$Q$</td>
<td>Quantity ordered</td>
<td>Pallet</td>
</tr>
<tr>
<td>$S_h$</td>
<td>Hourly salary of an inbound warehouse employee</td>
<td>€/hr</td>
</tr>
<tr>
<td>$t_{check}$</td>
<td>Time required to check a truck and transport documents</td>
<td>Minute</td>
</tr>
<tr>
<td>$t_o$</td>
<td>Overlapping time of replenishment actions</td>
<td>Day</td>
</tr>
<tr>
<td>$t_P$</td>
<td>Production time per delivered batch</td>
<td>Day</td>
</tr>
<tr>
<td>$t_{transit}$</td>
<td>Transit time</td>
<td>Day</td>
</tr>
<tr>
<td>$t_{unload}$</td>
<td>Time required to unload, check, label and store incoming pallets</td>
<td>Minute/pallet</td>
</tr>
<tr>
<td>$t_{QC}$</td>
<td>Quality control duration</td>
<td>Day</td>
</tr>
<tr>
<td>$U$</td>
<td>Utilization of a material</td>
<td>-</td>
</tr>
<tr>
<td>$v$</td>
<td>Volume per shipment</td>
<td>Pallet</td>
</tr>
<tr>
<td>$v_{FTL}$</td>
<td>Volume of a full truckload</td>
<td>Pallet</td>
</tr>
<tr>
<td>$\bar{v}_{pallet}$</td>
<td>Average pallet value</td>
<td>€/pallet</td>
</tr>
</tbody>
</table>
6.7 Sensitivity analysis

The previous section contained an overview of all developed general models, but these presented equations do not give insight in the important parameters. These important parameters are the ones that have a lot of influence on the output values of total costs and invested capital. To determine the importance of the parameters in an equation, the relative change of the input in percent is plotted against the relative change of the output in percent. A range of $-100\%$ to $+100\%$ for the input will be used in the sensitivity analysis. This method is applied for all five components in the coming paragraphs. In each of these paragraphs, the values used for the sensitivity analysis are presented as well. When the sensitivity analysis of all components is performed, a separate analysis will be performed to assess the relative importance of the transport, inventory, handling and ordering cost in the total inventory cost.

6.7.1 Transport cost

The equation used to calculate the transport cost between two points is:

$$C_{transport} = \left( p_{km} \left[ \frac{V}{V_{FTL}}, 1 \right] \cdot d_{ij} + (1 + L) c \right) + n_{stops} \cdot p_{docking} \cdot n_{trip}$$

In this equation $L$ indicates whether a shipment is a partial load ($L = 1$) or a full truckload ($L = 0$). One value is in this equation will be fixed, this is the full truckload volume $V_{FTL}$ and will be equal to 28 pallets. This also leads to the fact that $L = 1$ for $V \geq 28$. For all other parameters the following values are used:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{ij}$</td>
<td>Distance between point A and point B</td>
<td>500</td>
<td>Km</td>
</tr>
<tr>
<td>$c$</td>
<td>Empty kilometers after unloading</td>
<td>30</td>
<td>Km</td>
</tr>
<tr>
<td>$n_{stops}$</td>
<td>Number of stops in a route</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>$n_{trip}$</td>
<td>Number of trips performed on a lane per year</td>
<td>24</td>
<td>-</td>
</tr>
<tr>
<td>$p_{docking}$</td>
<td>Cost for docking a truck</td>
<td>30</td>
<td>€</td>
</tr>
<tr>
<td>$p_{km}$</td>
<td>Transportation price per km</td>
<td>1</td>
<td>€/km</td>
</tr>
<tr>
<td>$v$</td>
<td>Volume per shipment</td>
<td>17</td>
<td>Pallet</td>
</tr>
</tbody>
</table>

These values are used on a scale from $-100\%$ to $+100\%$, with a minimum of 1, and the number of stops is applied on a range from 1 to 4. In the end this results in the graph presented on the next page.

As could be expected, the most important input parameter is the number of trips per year $n_{trip}$, followed by the transport price $p_{km}$ and the distance $d_{ij}$. When considering the volume shipped, it can be seen that this is as important as the distance up to the point that a full truckload is shipped. When the volume exceeds the threshold value for a full truckload, the distance is more important since the volume is not affecting the transport cost any more. The other three parameters are having less influence on the transport cost.
When the same process is performed for the inventory costs with the equation and values presented below (table 6.3), it results in the graph depicted in figure 6.7 on the next page.

\[ C_{inventory} = U \cdot \frac{Q \cdot \left[ t_{qc}, t_{o} \right]}{t_{p} + \left[ 0, t_{qc} - t_{o} \right]} \cdot (\bar{v}_{pallet} \cdot p_{carrying} + p_{store}) \]  

(6.31)

Table 6.3: Standard values for the sensitivity analysis on inventory costs

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_{carrying} )</td>
<td>Carrying cost per euro of inventory per year</td>
<td>10</td>
<td>% of pallet value</td>
</tr>
<tr>
<td>( p_{store} )</td>
<td>Cost of physical storage per pallet location per year</td>
<td>100</td>
<td>€/pallet/year</td>
</tr>
<tr>
<td>( Q )</td>
<td>Quantity ordered</td>
<td>10</td>
<td>Pallet</td>
</tr>
<tr>
<td>( t_{o} )</td>
<td>Overlapping time of replenishment actions</td>
<td>5</td>
<td>Day</td>
</tr>
<tr>
<td>( t_{p} )</td>
<td>Production time per delivered batch</td>
<td>5</td>
<td>Day</td>
</tr>
<tr>
<td>( t_{qc} )</td>
<td>Quality control duration</td>
<td>5</td>
<td>Day</td>
</tr>
<tr>
<td>( U )</td>
<td>Utilization of a material</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>( \bar{v}_{pallet} )</td>
<td>Average pallet value</td>
<td>1000</td>
<td>€/pallet</td>
</tr>
</tbody>
</table>

When looking at these results, the graphs for the production time and quality check duration are caught by the eye when first looking at this figure. When the production time is getting infinitely small, the fraction that includes the production time in the denominator will lead to an infinitely large value for the fraction.
The duration of the quality control is only slightly relevant when this value is higher than the standard value used, because only in that case \([t_{qc}, t_o]\) and \([0, t_{qc} - t_o]\) will lead to \(t_{qc}\) and \(t_{qc} - t_o\) since the quality control takes longer than the overlapping time. Based on this statement it can be seen that this graph is also dependent on the value of the overlap time \(t_o\), because this statement only holds when \(t_{qc} = t_o\) in the initial situation.

Another thing that has to be kept in mind is that the relative importance of the cost of capital (\(\bar{v}_{\text{pallet}} \cdot \bar{p}_{\text{carrying}}\)) is dependent on the physical storage cost \(p_{\text{store}}\) and vice versa. However with the initial values selected, the replenishment quantity is most important followed by the overlap time. After the overlap time, the pallet value, holding cost and storage cost are the next in the ranking on the same position. No matter what values are chosen, the pallet value and the holding cost will always be equally important.

### 6.7.3 Handling cost

The sensitivity analysis performed for the handling cost results in the following ranking on importance:

1. Hourly salary of an inbound warehouse employee \(S_h\);
2. Number of pallets \(n_{\text{pallet}}\) / Unloading time \(t_{\text{unload}}\);
3. Number of trucks \(n_{\text{truck}}\) / Check time \(t_{\text{check}}\);

The results of figure 6.4 presented on the next page is obtained by using the data presented in table 6.4 and the following equation:

\[
C_{\text{handling}} = \frac{n_{\text{trucks}} \cdot t_{\text{check}}}{60} \cdot S_h + \frac{n_{\text{pallets}} \cdot t_{\text{unload}}}{60} \cdot S_h
\] (6.32)
Since no spectacular results were presented, the sensitivity analysis will continue with the ordering costs.

### 6.7.4 Ordering cost

The equation used to determine the ordering cost is a linear equation as can be seen:

\[ C_{\text{order}} = n_{\text{order}} \cdot P_{\text{order}} \]  

(6.33)

From this equation can be seen that an increase of either the number of orders \( n_{\text{order}} \) or the ordering costs \( P_{\text{order}} \), results in an increase of the ordering costs. So without performing a sensitivity analysis it can be seen that both parameters are equally important and a change of A% in one of these parameters will automatically lead to a change of the annual ordering costs with the same size A%. 

---

**Table 6.4: Standard values for the sensitivity analysis on handling costs**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_{\text{pallets}} )</td>
<td>Number of pallets that arrive per year</td>
<td>240</td>
<td>Pallet</td>
</tr>
<tr>
<td>( n_{\text{trucks}} )</td>
<td>Number of trucks that arrive per year</td>
<td>24</td>
<td>Truck</td>
</tr>
<tr>
<td>( S_h )</td>
<td>Hourly salary of an inbound warehouse employee</td>
<td>15 €/hr</td>
<td></td>
</tr>
<tr>
<td>( t_{\text{check}} )</td>
<td>Time required to check a truck and transport documents</td>
<td>10 Minute</td>
<td></td>
</tr>
<tr>
<td>( t_{\text{unload}} )</td>
<td>Time required to unload, check, label and store incoming pallets</td>
<td>3 Minute/pallet</td>
<td></td>
</tr>
</tbody>
</table>
6.7.5 Invested capital

The last model that has to be subjected to a sensitivity analysis is the one of invested capital. The equation (see equation 6.34) used to calculate the amount of invested capital has a similar structure as the one used to calculate the annual inventory costs, but then expanded with a term for the inventory that is still in transit.

\[
G = (\bar{T}_{cycle} + \bar{T}_{transit}) \cdot \bar{v} = \left( U \cdot \frac{Q \cdot [\tau_{qc}, \tau_{o}] + 2Q \cdot t_{p}}{t_{p} + [0, t_{qc} - t_{o}] + \frac{t_{transit}}{365} \cdot D} \right) \cdot \bar{v}_{pallet}
\]  

(6.34)

For this sensitivity analysis the same values are used as for the inventory cost analysis, completed with the values for the transit time of 7 hours and an annual demand of 240 pallets. All together this leads to figure 6.9 and shows results that are almost similar to the ones of the sensitivity analysis of the inventory cost. Again the production time is an important parameter when this is smaller than the duration of the quality control and the overlap. Furthermore the utilization and the pallet value are in general the most important parameters followed by the replenishment quantity.

![Figure 6.9: Result of the sensitivity analysis on invested capital](image)

Now that all individual models have been subjected to a sensitivity analysis it becomes essential to know the proportion between the models that together form the total costs. So this will be studied in the next paragraph.

6.7.6 Total cost analysis

The total cost function is a result of the transport, inventory, handling and ordering costs that have one or multiple parameter strongly influencing them. In this section it is determined which of these cost components has the largest influence on and share in the total costs. First of all, the costs are calculated with the same values as used in the previous paragraphs.
The calculation of the cost components results in:

- **Transport cost**
  - Value: €10166
  - Total cost share: 74%
- **Handling cost**
  - Value: €240
  - Total cost share: 2%
- **Inventory cost**
  - Value: €3000
  - Total cost share: 22%
- **Ordering cost**
  - Value: €360
  - Total cost share: 3%

As can be seen from the figures 74% of the total cost is a result of transporting the goods, after which there is a large gap to the inventory cost that has a share of 22%. From parameters used in the previous paragraphs it can be concluded are no parameters that are used in two cost components, so therefore these cost calculations are independent. Due to this fact, a simple sensitivity analysis can be performed in which only the values of the cost components are varied instead of the parameters. This results in the graph presented in figure 6.10 and is in line with the expectations based on the shares in the total cost of the different components.

From this figure it can be concluded that the most important component is the transport cost and thus also the number of trips, price per kilometer and distance are the most important parameters. Due to the large difference between the transport cost and the inventory cost, it is assumed that it is not necessary to perform a separate sensitivity analysis that is based on varying the values of the parameters of the individual models.

Since the models are changed to fit the concept situation and extra modules are added in the next chapter to build the complete concept performance models, a small sensitivity analysis will be performed when these changes are included to assess the impact. However this will all be done in the next chapter.
Chapter 7

Developing calculation models for concept performance assessment

In the previous chapter five general calculation models were developed to calculate the transportation costs, inventory costs, handling costs, ordering costs and the invested capital. These five models are modular components that will be used in this chapter for the development of calculation models for the four concepts to enable performance assessment. Besides the general models, there are also specific components required, so each of the four models will be completely developed in this chapter using the following order:

1. Milk-run
2. Cross-dock
3. Vendor Managed Inventory
4. Just-in-Time delivery

To assess the concept performance, the costs of the current situation have to be calculated as well. So this model will be presented first.

7.1 Current situation model

Before a conclusion can be drawn on the effect of one of the four inbound logistic concepts, the costs of the current situation have to be determined. This will mostly be done by using the general calculation models presented in the previous chapter. In this section the following order will be used to describe how the costs can be calculated:

- Transport costs
- Inventory costs
- Handling costs
- Ordering costs
- Invested capital

How these cost components are be calculated will be explained by presenting a number of steps with a short explanation, since the equations have been derived and extensively discussed in the previous chapter. The first step of calculating the current annual costs is the gathering the required data as can be seen on the next page.
• Step 1: List for every selected supplier:
  - The number of shipments per year $f_{c,\text{year},i}$
  - The average drop size $v_{c,i}$
  - The Cartesian grid coordinates $(x_i, y_i)$
  - Duration of the quality check $t_{qc}$
  - Utilization of the inventory $U_i$
  - Production time $t_{p,i}$ needed to consume $v_{c,i}$ completely
  - Overlap between replenishment actions $t_{o,i}$
  - Average pallet value $v_{\text{pallet}}$

To reduce the workload on collecting data, the production time $t_{p,i}$ can also be approximated by the following equation:

$$t_{p,i} = \frac{365}{f_{c,\text{year},i}}$$

(7.1)

• Step 2: Determine the total annual transportation costs

The most important component for the transport cost calculation is the distance the supplier $i$ to the factory $(d_{if})$ and can be calculated by:

$$d_{if} = \sqrt{(x_i - x_f)^2 + (y_i - y_f)^2} \cdot f_d \cdot f_u$$

(7.2)

With this distance, the annual transport costs for one supplier can be calculated by:

$$C_{\text{transport},i} = \left(p_{km} \left[\frac{v_{c,i}}{v_{\text{FTL}}}, 1\right] \cdot d_{if} + (1 + L)e\right) + 2 \cdot p_{\text{docking}} \cdot f_{c,\text{year},i}$$

(7.3)

With $L = \begin{cases} 1 & \text{if shipment is LTL} < v_{\text{FTL}}; \\ 0 & \text{if shipment is FTL} \geq v_{\text{FTL}}. \end{cases}$

When multiple suppliers are involved in a concept, which is the case for a milk-run and cross-docking, the total annual transport costs can be calculated by:

$$C_{\text{transport}} = \sum_i C_{\text{transport},i}$$

(7.4)

• Step 3: Determine the total annual inventory costs

The total inventory costs can be calculated using the following equation:

$$C_{\text{inventory}} = U_i \cdot \frac{Q \cdot t_{qc,s}}{t_p + [0, t_{qc} - t_{o,s}]} \cdot (v_{\text{pallet}} \cdot p_{\text{carrying}} + p_{\text{store}})$$

(7.5)

By substituting the ordered quantity $Q$ by the average drop size $v_{c,i}$ of supplier $i$ and specifying all other components for supplier $i$, this leads to:

$$C_{\text{inventory},i} = U_i \cdot \frac{v_{c,i} \cdot t_{qc,i} \cdot t_{o,i}}{t_{p,i} + [0, t_{qc,i} - t_{o,i}]} \cdot (v_{\text{pallet},i} \cdot p_{\text{carrying}} + p_{\text{store}})$$

(7.6)

And in case of more than one supplier:

$$C_{\text{inventory}} = \sum_i C_{\text{inventory},i}$$

(7.7)
• Step 4: Determine the annual handling cost

In the same way as for the inventory costs, the equation can be adapted with the following substitutions: (1) \( n_{\text{trucks}} = f_{\text{c, year}, i} \) and (2) \( f_{\text{pallets}} = f_{\text{c, year}, i} \cdot v_{\text{c}, i} \). This leads to:

\[
C_{\text{handling}, i} = \frac{f_{\text{c, year}, i} \cdot t_{\text{check}}}{60} \cdot S_h + \frac{f_{\text{c, year}, i} \cdot v_{\text{c}, i} \cdot t_{\text{unload}}}{60} \cdot S_h
\]

(7.8)

\[
C_{\text{handling}} = \sum_i C_{\text{handling}, i}
\]

(7.9)

• Step 5: Determine the annual ordering cost

By replacing \( n_{\text{order}} \) by \( f_{\text{c, year}, i} \) the equation for the annual ordering costs becomes:

\[
C_{\text{order}, i} = f_{\text{c, year}, i} \cdot P_{\text{order}}
\]

(7.10)

\[
C_{\text{order}} = \sum_i C_{\text{order}, i}
\]

(7.11)

• Step 6: Determine the total invested capital

In the current situation, the goods are owned by the supplier during transport. So the component in the invested capital equation presented in previous chapter that deals with transportation inventory can be eliminated. When the component of the average inventory level in the invested capital equation is replaced by the part of the annual inventory costs that represents the average inventory level, this adds up to:

\[
G_i = U_i \cdot \frac{v_{\text{c}, i} \cdot [t_{\text{qc}, i}, t_{\alpha, i}]}{t_{p, i}} \cdot \frac{v_{\text{c}, i} \cdot t_{\text{p}, i}}{2} \cdot \frac{v_{\text{pallet}, i}}{t_{\text{p}, i} + [0, t_{\text{qc}, i} - t_{\alpha, i}]} \cdot v_{\text{pallet}, i}
\]

(7.12)

\[
G = \sum_i G_i
\]

(7.13)

By using these six steps, the current cost components and invested capital can be calculated for every scenario. From now on the models are presented that calculate the costs and invested capital for a specific situation starting with a milk-run.

7.2 Milk-run model

Despite that the milk-run principle was already explained in chapter 4, it will be shortly recalled here so that the steps for the calculation model development are understood more easily. A milk-run is a collection route of one truck that picks-up partial loads at multiple locations. When all locations in the predefined route are served, the truck will continue to the factory. The route that serves all suppliers can be chosen randomly but this will have a high probability of ending up with a suboptimal route. So one component of the milk-run model that has to be discussed in this section will determine the optimal route; thereby minimizing the total distance needed to serve all suppliers.

Another result of the fact that all suppliers are served in one route, is that all loads have to be picked-up at the same date with the same frequency. Currently different dates and frequencies are used for various suppliers, so another module of the milk-run model needs to determine the new order frequency which then leads to different drop sizes.

The calculation model that enables an assessment of the milk-run performance will be constructed by first developing the routing and synchronization module. These are then combined with the general models that will need some adaptations for the milk-run situation. When the model is developed, an overview will be presented by means of a flowchart and a sensitivity analysis is performed.
7.2.1 Vehicle routing

The problem that has to be solved for the milk-run, is that the total distance required to serve all suppliers and to finally drive to the factory is minimized. According to literature this can be classified as the "Travelling Salesman Problem (TSP)" for which Laporte (1992) stated that this is one of the most widely studied combinatorial optimization problems that is easy to formulate but challenging to solve. Dantzig et al. (1954) define the Travelling Salesman Problem as:

"Find the shortest route (tour) for a salesman starting from a given city, visiting each of a specified group of cities, and then returning to the original point of departure. More generally, given an n by n symmetric matrix $D = (d_{ij})$, where $d_{ij}$ represents the 'distance' from $i$ to $j$, arrange the points in a cyclic order in such a way that the sum of the $d_{ij}$ between consecutive points is minimal."

With the following exact algorithm of Dantzig et al. (1954), which is one of the earliest formulations on this problem according to Laporte (1992). In this formulation one binary variable $x_{ij}$ is associated with every arc $(i,j)$ and equals 1 if and only if $(i,j)$ is used in the optimal solution with $i \neq j$.

$$\text{Minimize } \sum_{i \neq j} c_{ij} x_{ij}$$  \hspace{1cm} (7.14)

Where $c_{i,j}$ is the weight of the arc between $i$ and $j$. This minimization function is subjected to:

$$\sum_{j=1}^{n} x_{ij} = 1, \quad i = 1, ..., n,$$  \hspace{1cm} (7.15)

$$\sum_{i=1}^{n} x_{ij} = 1, \quad j = 1, ..., n,$$  \hspace{1cm} (7.16)

$$\sum_{i,j \in S} x_{ij} \leq |S| - 1, \quad S \subseteq V, \quad 2 \leq |S| \leq n - 2,$$  \hspace{1cm} (7.17)

$$x_{ij} \in \{0, 1\}, \quad i, j = 1, ..., n, \quad i \neq j.$$  \hspace{1cm} (7.18)

Equations 7.15 and 7.16 state that every location is only used once as a destination and as an origin. Equation 7.17 eliminates the possibility of a subtour (a closed loop that is not connected to other points) on a subset $S$ of vertices. Equation 7.18 imposes binary conditions on the variables. Laporte (1992) states that it is unrealistic to solve the formulation of Dantzig et al. (1954) by means of linear programming.

Though there are some differences between a milk-run and the Travelling Salesman Problem. First of all the milk-run has a starting and end point that are not the same location, whereas the Travelling Salesman Problem begins and finished at the same location. But the truck driver will finally return to its origin therefore leading to the conclusion that a milk-run will be one a part in a roundtrip and is therefore part of a Travelling Salesman Problem. The milk-run can be translate to a Travelling Salesman Problem by setting all distances from the factory to the other locations on zero, thereby creating a loop without adding any distance to the route.

Whereas the starting point in a Travelling Salesman Problem is known, its hometown, this point has to be determined in a milk-run. The only fixed component in the route is the destination, which is the factory. But when using a looped milk-run (by setting the distance from the factory to zero as mentioned), the optimal loop will be determine for which the starting point of the milk-run will be the first supplier served after the factory in this loop.
Another more time consuming method to determine the shortest route is by using a tree diagram. Normally this starts at an origin, in case of the Travelling Salesman Problem his hometown, but since the only fixed point in a milk-run is the factory as a destination, it will have a reversed orientation.

Figure 7.1: A tree diagram of possible routes for a cluster with 3 suppliers and one factory

When considering the practical application of a tree diagram at Danone Baby Nutrition, it became clear that almost all clusters contained 5 or less suppliers. This results in 120 feasible routes, which is considered to be of allowable size to include in Excel with a tree diagram. To allow possible larger clusters, up to 6 suppliers can be included in the model for a milk-run. The model will calculate the total distance of all the 720 resulting routes, determines the route with the minimal distance and displays this route with the total distances. This is done by the following three steps:

- Step 1: Construct a distance matrix $D$ based on the coordinates of the suppliers and the factory using:
  \[ D = (d_{ij}) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \cdot f_d \cdot f_u \]  
  \[ (7.19) \]

- Step 2: Determine the total distance of all possible routes by using the distance matrix;

- Step 3: Find the route with the minimal total distance ($D_m$ [km]) and display the order of this route.

The number of possible routes rapidly increases with an increasing number of suppliers ($n_{suppliers}$) as can be seen in table 7.1 on the next page that follows equation 7.20. In the exceptional case that a cluster will contain 7 or more suppliers, an additional tool ("Optimize add-in") for Excel is available for download on the internet at http://www.me.utexas.edu/~jensen/ORMM/excel/optimize.html. This tool can be used to determine the optimal route for larger problems and offers the possibility to do this based on either the coordinates of the suppliers or a distance matrix. The disadvantage of this model is that is literally solving the Travelling Salesman Problem and thus it has to be manipulated, as mentioned before, by setting the distances from the factory to the suppliers to zero ($d_{fi} = 0$).

\[ n_{routes} = (n - 1)! = n_{suppliers}! = 1 \cdot 2 \cdot 3 \cdot 4 \cdot ... \cdot n \]  
\[ (7.20) \]
Transport costs

To calculate the transport costs involved with a milk-run, both the routing and the order synchronization module are required to provide the needed data. The equation needed for the transportation costs is presented here again:

$$C_{transport} = \left( \frac{p_{km}}{v_c/v_{FTL}} \right) \cdot d_{ij} + (1 + L) \cdot e + n_{stops} \cdot p_{docking} \cdot n_{trip}$$  \hspace{1cm} (7.26)

With \( L \) being 1 if shipment is LTL (\( < v_{FTL} \)); 0 if shipment is FTL (\( \geq v_{FTL} \)).

With exception of the part between the last pick-up address in a milk-run and the factory all parts involve partial loads for which the following equation should be used since \( L = 1 \) in this case:

$$C_{transport,LTL} = \left( \frac{p_{km}}{v_c/v_{FTL}} \right) \cdot d_{ij} + 2e + n_{stops} \cdot p_{docking} \cdot n_{trip}$$  \hspace{1cm} (7.27)

For the last transport part in the milk-run the next formula should be used:

$$C_{transport,FTL} = \left( p_{km} \cdot d_{ij} + e \right) \cdot n_{stops} \cdot p_{docking} \cdot n_{trip}$$  \hspace{1cm} (7.28)

However, the surcharge in the LTL equation was used to cover potential distance that has to be travelled to pick-up another partial load in the situation that only one partial load was shipped from location \( A \) to \( B \). In case of milk-run, these next partial loads are already offered and the distance travelled between the different suppliers is paid as well. So in this case the FTL equation can be used.

When taking a closer look at these equations, a number of terms can be replaced by others that are output from the synchronization and routing modules. First of all, the distance travelled between two locations \( d_{ij} \) can be replace by the total distance travelled in a milk-run \( D_m \). The number of stops will be equal to the number of suppliers plus 1 because the first stop is at the first pick-up address and the last stop is at the factory, in between the truck stops once at every supplier. Finally the number of trips \( n_{trip} \) is equal to the total number of deliveries \( f_{m,year} \) calculated by the synchronization module. In the end, the equation that can be used to determine the transport cost of a milk-run is:

$$C_{m,transport} = \left( \frac{p_{km}}{v_c/v_{FTL}} \right) \cdot D_m + e \cdot (n_{suppliers} + 1) \cdot p_{docking} \cdot f_{m,year}$$  \hspace{1cm} (7.29)

Inventory costs

As can be seen from equation 7.30, the inventory cost of the cycle stock per supplier is dependent on multiple variables. The most important ones influenced here, are the ordered quantity \( Q \) and the production time \( t_p \) needed to consume \( Q \).

$$C_{cycle} = U \cdot \frac{Q \cdot [t_{qc, t_o}] + 0.5 \cdot Q \cdot t_p}{t_p + [0, t_{qc} - t_o]} \cdot (v_{pallet} \cdot p_{carrying} + p_{store})$$  \hspace{1cm} (7.30)

The quantity ordered in a milk-run scenario is equal to the new average drop size \( v_{m,i} \). The production time \( t_p \) is dependent on the order quantity and can be replaced in this case by: \( t_{p,i} \cdot v_{m,i}/v_{c,i} \). So the annual stock costs for supplier \( i \) can be determined by:

$$C_{inventory,i} = U \cdot \frac{v_{m,i} \cdot [t_{qc,i}, t_{o,i}] + 0.5 \cdot v_{m,i} \cdot t_{p,i} \cdot v_{m,i}/v_{c,i}}{t_{p,i} \cdot v_{m,i}/v_{c,i} + [0, t_{qc,i} - t_{o,i}]} \cdot (v_{pallet,i} \cdot p_{carrying} + p_{store})$$  \hspace{1cm} (7.31)
To calculate the total inventory costs for a cluster, the sum of the costs of the suppliers has to be taken:

\[ C_{m,\text{inventory}} = \sum_{i} C_{\text{inventory},i} \]  

(7.32)

With the equation the description of how to calculate the inventory cost for a milk-run is finished.

Handling costs

The handling cost is a function of the number of trucks that arrive at a factory and the yearly number of pallets that have to be unloaded. Therefore only part of the handling cost is influenced since the number of pallets that is delivered on a yearly basis remains the same and is equal to \( \sum V_i \). The part of the handling cost that is changing is the part that is concerned with the number of trucks, which is dependent on the total annual demand and the number of pallets that fit into one truck. In the end the number of trucks can be expressed as \( \sum V_i/v_{\text{truck}} \), leading to:

\[ C_{m,\text{handling}} = \frac{f_{m,\text{year}} \cdot t_{\text{check}}}{60} \cdot S_h + \frac{t_{\text{unload}} \cdot \sum V_i}{60} \cdot S_h \]  

(7.33)

Ordering costs

By changing the number of yearly deliveries, the number of orders placed will change as well and thereby also the ordering costs. The total annual ordering costs are calculated by the following equation where the number of orders \( n_{\text{order}} \) equals the yearly amount of deliveries:

\[ C_{\text{order}} = n_{\text{order}} \cdot P_{\text{order}} \]  

(7.34)

When a milk-run is used, an extra component has to be included due to the fact that the transportation has to be arranged by Danone Baby Nutrition whereas this was previously done by the supplier. So when the initial time needed to inform the logistic service provider is neglected, there is only a fixed time needed every time to arrange the milk-run. In this time the suppliers are informed about the pick-up and the logistic service provider updated on the route and the pick-up quantities.

The number of orders placed is equal to \( f_{m,\text{year}} \cdot n_{\text{suppliers}} \), whereas the costs involved with arranging a milk-run once can be expressed by \( S_o \cdot t_m/60 \) in which \( S_o \) is the hourly salary of a buyer that arranges the milk-run (€/hour) and \( t_m \) the time needed to perform this task in minutes. This leads to the next equation to determine the annual ordering costs for a milk-run:

\[ C_{m,\text{order}} = f_{m,\text{year}} \left( n_{\text{suppliers}} \cdot P_{\text{order}} + S_o \cdot t_m/60 \right) \]  

(7.35)

Invested capital

The last component of the milk-run model is concerned with the invested amount of capital in inventory. The general equation to calculate the amount of capital was:

\[ G = \left( U \cdot \frac{Q \cdot [t_{\text{qc}},t_o]}{t_p + \left| 0, t_{\text{qc}} - t_o \right|} + 0.5 \cdot Q \cdot t_p + t_{\text{transit}}/365 \cdot D \right) \cdot \bar{v}_{\text{pallet}} \]  

(7.36)

The first component is related to the average amount of cycle stock kept and can be replaced by the following formula that is in line with equation 7.31:

\[ U_i \cdot \frac{v_{m,i} \cdot [t_{\text{qc}},t_o]}{t_p,i \cdot v_{m,i} \cdot v_{c,i} + \left| 0, t_{\text{qc}} - t_o,i \right|} + 0.5 \cdot v_{m,i} \cdot t_{p,i} \cdot v_{m,i} \cdot v_{c,i} \]  

(7.37)

The last component is related to the transit time of the goods. In the current situation the supplier still owns the goods during transport, however in a milk-run the buyer, in this case Danone Baby
Nutrition, owns the goods. So therefore the transit time has to be calculated which is dependent on the distance of the milk-run $D_m$, the average speed of the truck $s_{truck}$ and the maximum hours that are allowed be driven by one truck driver in one day $t_{drive}$. The latter value can be set on 9 hours to be in line with the Dutch law on driving times (Inspectie Verkeer en Waterstaat, 2011). This results in:

$$t_{transit} = \left( \frac{D_m}{s_{truck}} \right) \cdot \frac{1}{t_{drive}}$$

And thus the total invested amount of capital can be expressed by:

$$G_m = \sum_i \left( U_i \cdot \frac{v_{m,i} \cdot [t_{qc,i}, t_{o,i}]}{t_{p,i} \cdot v_{m,i} / v_{c,i}} + 0.5 \cdot v_{m,i} \cdot t_{p,i} \cdot v_{m,i} / v_{c,i} + \frac{D_m}{s_{truck} \cdot t_{drive}} \right) \cdot \bar{V}_i \cdot \bar{v}_{pallet,i}$$

**Flowchart of the milk-run model**

In the previous paragraphs the five general calculation models have been adapted for the milk-run situation. In this paragraph a flowchart is presented that contains all information about the connections between the different modules of the milk-run model and the required in- and the output of the components.

In figure 7.2 the flowchart of the milk-run model is presented. To keep this flowchart understandable, only symbols are used to display the input, output and intermediate data. In tables 7.4, 7.5 and 7.6 these symbols can be found. Table 7.4 contains the data that has to be gathered from every supplier, but simplified by skipping the $i$ that indicates supplier $i$, which leads to $v_c$ instead of $v_{c,i}$. Tables 7.5 and 7.6 contain the general symbols and the ones used for the output.
With this flowchart the complete milk-run model is described, but due to the two extra modules in addition to the five general models an expansion of the sensitivity analysis is needed. This sensitivity analysis will be performed in the next section.

### 7.2.4 Milk-run sensitivity analysis

The extra modules of the milk-run model are the ones that determine the route and synchronize the order. The influence of the number of shipments per year has already become clear in the standard sensitivity analysis. In this sensitivity analysis the effect of a milk-run is studied in more detailed by comparing the effect of the distance between the suppliers, the distance from the suppliers to the factory and the number of suppliers.

For this sensitivity analysis a fictive situation is used in which the standard distance from all four suppliers to the factory is 500 km ($d_{ij}$) and they all ship 8 pallets at a time. The distance from a supplier to the next supplier within the route of 4 suppliers ($n_{suppliers}$) is equal to 25 km ($d_{ij}$) and will only focus at the transport costs at first instance. This is done because this cost component has the largest share in the total costs as was calculated in the previous chapter. It
should be noted here, that the suppliers are thus located on a circle with a radius of 500 km since it is assumed that all suppliers are located at the same distance. This results in the following constraint:

\[ n_{\text{suppliers}} \cdot d_{ij} \leq 2\pi \cdot d_{ij} \quad (7.40) \]

And means that varying the parameter values is limited to:

- Distance from the suppliers to the factory (lower bound): 16 km
- Distance between suppliers (upper bound): 785 km
- Number of supplier (upper bound): 125 suppliers

These upper and lower bounds are based on the above presented initial values. From these values it can be made up that this has no influence on the sensitivity analysis because \( d_{ij} = 0 \) and \( d_{ij} = 0 \) are excluded. The values are excluded because they are unrealistic and the parameters will be maximally twice their initial value, thereby staying far under the upper bounds.

Before the sensitivity analysis is performed, a distinction is made between the results that can be calculated. The following effects of the distance between suppliers, to the factory and the number of supplier can be evaluated:

1. Milk-run transport cost
2. Size of the cost reduction realized by the milk-run
3. Relative cost reduction realized by the milk-run

Determining the effect on the milk-run transport cost gives a good impression of the relation between parameters and this transport cost and is actually a real sensitivity analysis and should thus be included. However by changing the parameters as the number of suppliers and the distance to the factory is also influencing the current costs, so therefore the researcher finds it useful to take a look at the relative cost reduction as well between the current and future costs.

First the results are presented of the sensitivity analysis on the current and future situation in figure 7.3. From this figure it can be seen that in the current situation the number of suppliers has more influence compared to the distance from the suppliers to the factory, whereas the opposite is true in the milk-run situation. Also in the milk-run situation, the output is less sensitive compared to the current situation and is also sensitive to the distance between the suppliers.

![Figure 7.3: Results of the milk-run sensitivity analysis on transport cost](image)
More important for the selection of suppliers for a milk-run concept is the effect of the parameters on the cost savings that can be realized. Thereby including both the current and future situation by looking at the difference. This is done by looking at the size of the cost reduction as a percentage of the current annual transport cost. This results in the figure 7.4.

![Figure 7.4: Milk-run parameter effectiveness](image)

Based on this figure it can be concluded that the most optimal value will occur when:

- The number of suppliers is maximal
- The distance to the factory is maximal
- The distance between suppliers is minimal

Up to this point, the focus of this sensitivity analysis was only on the transport costs because it was calculated that this accounted for 74% of the total costs. However with the transport cost reduction indicated in this sensitivity analysis of about 30% this should be reassessed. Recalculating the share in the clusters total cost leads to:

<table>
<thead>
<tr>
<th>Current situation:</th>
<th>Handling cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Transport cost</td>
<td>- Value: €960</td>
</tr>
<tr>
<td>* Value: €25234</td>
<td>* Total cost share: 3%</td>
</tr>
<tr>
<td>* Total cost share: 68%</td>
<td></td>
</tr>
<tr>
<td>- Inventory cost</td>
<td>- Ordering cost</td>
</tr>
<tr>
<td>* Value: €9600</td>
<td>* Value: €1440</td>
</tr>
<tr>
<td>* Total cost share: 26%</td>
<td>* Total cost share: 4%</td>
</tr>
</tbody>
</table>

2The parameter values used can be found in appendix E
• Milk-run situation:
  - Transport cost
    * Value: €18120
    * Total cost share: 58%
  - Inventory cost
    * Value: €9600
    * Total cost share: 30%
  - Handling cost
    * Value: €636
    * Total cost share: 2%
  - Ordering cost
    * Value: €3060
    * Total cost share: 10%

In this situation, where the number of replenishment actions remains constant at 24 deliveries per year, the inventory levels are not influenced and thus the gain in importance of the inventory costs is maximal. Still the share of the transport costs is almost twice the share of the inventory cost.

Despite that the extra component in the ordering cost results in a higher share of the ordering cost, the influence of this extra term on the total cost is still small. Therefore it is decided not to perform a separate sensitivity analysis for this term.

7.3 Cross-dock model

The goal of cross-docking is similar to the one of a milk-run, to consolidate shipments and reduce the inbound logistic costs. However where only one truck is used to collect the shipments in a milk-run, multiple trucks are used in a cross-dock situation to ship the goods to one location where they are transshipped into one truck that drives to the final destination.

Resulting from the fact that the goods are shipped to one location, this location has to be found in a way that it minimizes the total transport cost with this setup. So one component of the cross-dock model has the task to determine the location of this cross-dock facility. As with the milk-run, also for the cross-dock concept the orders have to be synchronized, for this purpose the same synchronization model will be used as presented in paragraph 7.2.2 with the following equations:

\[ V_i = v_{c,i} \cdot f_{c,year,i} \]  
\[ f_{cross,year} = \frac{\sum V_i}{v_{truck}} \]  
\[ v_{cross,i} = \frac{f_{c,year,i}}{f_{cross,year}} \cdot v_{c,i} \]

For the concept performance assessment model for cross-docking, which will be presented in this section, the same structure as in the last section will be maintained. So first the facility location module will be presented, after which this module is combined with the general calculations model. These general models need to be adapted first for the cross-dock situation and then a flowchart of the complete model will be presented.

7.3.1 Cross-dock facility location

As was already explained, cross-docking is a concept in which multiple suppliers ship their products to a facility that transships them into another truck, thereby combining loads. In theory there is one location that is optimal for placing such a facility from a number of perspectives. Factors such as the availability and access of transportation, labour climate, proximity to the markets and customers have to be taken into account according to Langley et al. (2009).
In logistic literature the grid method, also called center of gravity method, is a commonly used heuristic approach that can be used as a first step in a facility allocation problem, see Langley et al. (2009) and Reid and Sanders (2007). This technique assumes that the suppliers and markets are fixed, which is completely in line with the scoping presented in chapter 2 and determines the best location based on horizontal and vertical grid coordinates of markets and customers, or suppliers and factories.

The coordinates of the ton-mile center, or center of mass, can be calculated by (Reid and Sanders, 2007):

\[ X_{c.g.} = \frac{\sum V_i x_i}{\sum V_i} \]  
\[ Y_{c.g.} = \frac{\sum V_i y_i}{\sum V_i} \]

With:  
\( (x_i, y_i) \) Cartesian coordinates of supplier \( i \)  
\( V_i \) Yearly volume of supplier \( i \)

Despite the fact that this method often used and a widely presented method in scientific literature used for education, it was already proven in 1973 by Schärlig (1973) that the grid method is not leading to the optimal location. Weber’s method on the contrary is leading to the optimal facility location and is based on the following minimization function in Cartesian coordinates (adapted from Schärlig, 1973):

\[ \text{Minimize } F = V_i \sqrt{(x - x_i)^2 + (y - y_i)^2} \]

In order to find the minimum of this function, the following partial derivatives with respect to \( x \) and \( y \) have to be equal to zero:

\[ \frac{\delta F}{\delta x} = \sum_{i=1}^{n} V_i \frac{x - x_i}{\sqrt{(x - x_i)^2 + (y - y_i)^2}} = 0 \]  
\[ \frac{\delta F}{\delta y} = \sum_{i=1}^{n} V_i \frac{y - y_i}{\sqrt{(x - x_i)^2 + (y - y_i)^2}} = 0 \]

These two functions cannot be solved mathematically and thus need an iterative procedure. In Schärlig (1973) the following formulas for this iterative procedure are presented based on the partial derivatives presented above:

\[ x^{(k+1)} = \frac{\sum_{i=1}^{n} V_i x_i / \sqrt{(x^{(k)} - x_i)^2 + (y^{(k)} - y_i)^2}}{\sum_{i=1}^{n} V_i / \sqrt{(x^{(k)} - x_i)^2 + (y^{(k)} - y_i)^2}} \]  
\[ y^{(k+1)} = \frac{\sum_{i=1}^{n} V_i y_i / \sqrt{(x^{(k)} - x_i)^2 + (y^{(k)} - y_i)^2}}{\sum_{i=1}^{n} V_i / \sqrt{(x^{(k)} - x_i)^2 + (y^{(k)} - y_i)^2}} \]

Based on the publication of Schärlig (1973), in which it is proven that Weber’s method is the correct method to determine the least cost location of a facility, the conclusion is drawn that the Weber’s method will result in a lower amount of total kilometers driven. This difference can reach up to 15% with the center of gravity method and is considered to be significant by the researcher.

However, an iterative procedure starts with an initial estimate of the location coordinates. Instead of using a random guess for these initial coordinates, the grid method is used to calculate the starting coordinates for the first iteration. This improves the accuracy after a limited number of iterations e.g. 5 iterations.
To determine the optimal location of a cross-dock facility the following steps should be taken:

- Step 1: Obtain Cartesian coordinates of suppliers;
- Step 2: Determine the center of gravity;
- Step 3: Iteratively determine the optimal location with Weber’s method with the center of gravity as the starting point.

So this method makes it possible to determine the optimal facility location. For the simple Microsoft Excel model that will be used by Danone Baby Nutrition, it was chosen by the researcher that the number of iterations used to determine the facility location will be limited to 50. Since normally a stopping criteria is used that stops the iterations when a certain precision is reached, the absolute difference between iteration 49 and 50 will be displayed as output. With this final comment on the facility location module, the complete model can be created in the next paragraph.

7.3.2 Creating the complete cross-dock performance model

Besides the two components to determine the cross-dock facility location and to synchronize the shipments, the general calculation models will also be part of the performance model. Therefore these general models are now adapted if needed to this specific situation. When this is finished, the flowchart can be created that describes how the cross-docking model works, but now first the transport cost calculation is specified.

Transport costs

Two separate trips can be identified in the transportation of goods from the supplier to the factory in a cross-docking arrangement. The first one is from the supplier to the cross-dock facility in less-than-truckloads and the second one is from the cross-dock facility to the factory in full truckloads. For both parts a different equation holds due to the different load factor. In line with the way this was done for the milk-run the following two equations are valid.

- For the transport from supplier \( i \) to the cross-dock facility:
  
  \[
  C_{\text{transport},i} = \left( p_{\text{km},c} \left[ \frac{v_{\text{cross},i}}{v_{\text{FTL},1}} \right] \cdot d_{ic} + 2e \right) + 2 \cdot p_{\text{docking}} \cdot f_{\text{cross,year}}
  \]

- For the transport from the cross-dock facility to the factory:
  
  \[
  C_{\text{transport},c} = \left( p_{\text{km}} \left[ d_{cf} + e \right] + 2 \cdot p_{\text{docking}} \right) \cdot f_{\text{cross,year}}
  \]

It should be noted here that there is a different price per kilometer \( p_{\text{km},c} \) introduced in the first equation. This is done because in a cross-dock arrangement the point of transhipment will be located closer to the suppliers, resulting in lower distances. This might mean that smaller trucks are used since it are all partial loads and this will result in a different price per kilometer driven. The distances \( d_{ic} \) and \( d_{cf} \) are respectively the distance between supplier \( i \) and the cross-dock facility and the distance between this facility and the factory.

When this is combined this will lead to this cross-docking transport cost function:

\[
C_{\text{c,transport}} = C_{\text{transport},c} + \sum_i C_{\text{transport},i} = \left( p_{\text{km}} \left[ d_{cf} + e \right] + 2 \cdot p_{\text{docking}} \right) \cdot f_{\text{cross,year}} + \sum_i \left( p_{\text{km},c} \left[ \frac{v_{\text{cross},i}}{v_{\text{FTL},1}} \right] \cdot d_{ic} + 2e \right) + 2 \cdot p_{\text{docking}} \cdot f_{\text{cross,year}}
\]
Inventory costs

Using the cross-docking concept will lead to another replenishment frequency compared to the current frequency and thus will the inventory costs change. From this perspective there is no difference between a milk-run or cross-docking so therefore the same equation can be used:

\[ C \text{cycle,}i = U_i \cdot \frac{v_{cross,i} \cdot [t_{qc,i}, t_{o,i}]}{t_{p,i} \cdot v_{cross,i}/v_{c,i} + [0, t_{qc,i} - t_{o,i}]} \cdot (\bar{p}_{\text{pallet,}i} \cdot p_{\text{carrying}} + p_{\text{store}}) \]

(7.54)

\[ C_{c,\text{cycle}} = \sum_i C_{\text{cycle,}i} \quad (7.55) \]

Handling costs

By transhipping the goods from one truck to another in order to consolidate shipments, an extra handling activity is added. So now the goods are not only handled at the factory, but also at the cross-dock facility. This cross-docking is only performed for a couple of clusters at the most and not for the complete inbound flow. Therefore this activity will not be performed by Danone Baby Nutrition but outsourced to a logistic service provider. Danone Baby Nutrition has to pay this logistic service provider for transhipping the pallets and it is assumed by the researcher that a fixed charge \( p_c \) of €3 per pallet will be applied (van der Vlist, 2007). This extra charge has to be added to the standard handling cost equation, resulting in:

\[ C_{c,\text{handling}} = \frac{f_{cross,year} \cdot t_{check}}{60} \cdot S_h + \frac{t_{unload} \cdot \sum_i V_i}{60} \cdot S_h + p_c \cdot \sum_i V_i \quad (7.56) \]

Ordering costs

Again in a similar way as for a milk-run, the standard ordering costs are dependent on the number of shipments each year and the number of suppliers that participate in a cross-dock cluster. Also here an additional component is needed to include the costs involved with arranging the shipments so that they can be cross-docked. However, the time constraint is limited to a part of the day (for example the morning of 6 September) and thus less time will be needed to arrange this compared to a milk-run. Finally this leads to:

\[ C_{c,\text{order}} = f_{cross,year} \cdot \left( n_{\text{suppliers}} \cdot p_{\text{order}} + S_o \cdot \frac{t_{cross}}{60} \right) \quad (7.57) \]

Invested capital

All cost components have been set to match the cross-dock situation, so now the last general calculation model on the invested capital will be adapted. It should be realized that the goods are owned by Danone Baby Nutrition at the moment they are unloaded at the cross-dock facility. This leads to the following equation that is almost equal to the one of the milk-run:

\[ G_c = \left( U_i \cdot \frac{v_{cross,i} \cdot [t_{qc,i}, t_{o,i}]}{t_{p,i} \cdot v_{cross,i}/v_{c,i} + [0, t_{qc,i} - t_{o,i}]} + \frac{d_{\text{truck}}} {365 \cdot \text{truck}} \cdot \sum_i V_i \right) \cdot \bar{p}_{\text{pallet,}i} \]

(7.58)

Cross-docking model flowchart

Despite the fact that all individual parts of the cross-dock model have been described, there is no clear connection between them. To illustrate these connections and to generate an overview of the model, a flowchart is presented. This is done again by a figure and supporting tables with
the symbols used. This flowchart is again almost similar to that one of the milk-run, however the facility location module is new, some symbols have changed and there are new symbols introduced. In figure 7.5 the flowchart of the cross-docking model is presented with the symbols described in tables 7.8, 7.7 and 7.9.

Figure 7.5: Flowchart of the cross-dock performance assessment model

Table 7.7: General input symbols of the cross-dock flowchart

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e$</td>
<td>Empty kilometers after unloading</td>
<td>$S_h$</td>
<td>Hourly salary of an inbound warehouse employee</td>
</tr>
<tr>
<td>$p_c$</td>
<td>Cost of cross-docking per pallet</td>
<td>$S_o$</td>
<td>Salary of a buyer</td>
</tr>
<tr>
<td>$p_{carrying}$</td>
<td>Carrying cost per euro of inventory per year</td>
<td>$s_{truck}$</td>
<td>Average truck speed</td>
</tr>
<tr>
<td>$p_{docking}$</td>
<td>Cost for docking a truck</td>
<td>$t_{check}$</td>
<td>Time required to check a truck and transport documents</td>
</tr>
<tr>
<td>$p_{km}$</td>
<td>Transportation price per km</td>
<td>$t_{cross}$</td>
<td>Time needed to arrange cross-dock</td>
</tr>
<tr>
<td>$p_{km,c}$</td>
<td>Transportation price per km from supplier to cross-dock facility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p_{order}$</td>
<td>Ordering cost per order</td>
<td>$t_{drive}$</td>
<td>Maximum hours that can be driven in one day</td>
</tr>
<tr>
<td>$p_{store}$</td>
<td>Annual cost of physical storage per item</td>
<td>$t_{unload}$</td>
<td>Time required to unload, check, label and store incoming pallets</td>
</tr>
<tr>
<td>$v_{truck}$</td>
<td>Pallets per truck</td>
<td>$v_{truck}$</td>
<td>Pallets per truck</td>
</tr>
</tbody>
</table>
Table 7.8: Supplier related input symbols of the cross-dock flowchart

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_{c,\text{year}} )</td>
<td>Current total deliveries per year</td>
</tr>
<tr>
<td>( n_{\text{suppliers}} )</td>
<td>Number of suppliers</td>
</tr>
<tr>
<td>( t_{qc} )</td>
<td>Duration quality check</td>
</tr>
<tr>
<td>( t_o )</td>
<td>Overlap</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U )</td>
<td>Product utilization</td>
</tr>
<tr>
<td>( v_c )</td>
<td>Current average drop size</td>
</tr>
<tr>
<td>( \bar{v}_{\text{pallet}} )</td>
<td>Average pallet value</td>
</tr>
<tr>
<td>( (x, y) )</td>
<td>Cartesian grid coordinates</td>
</tr>
</tbody>
</table>

Table 7.9: Output symbols of the cross-dock flowchart

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d_{i,c} )</td>
<td>Distance from supplier ( i ) to the cross-dock facility</td>
</tr>
<tr>
<td>( d_{c,f} )</td>
<td>Distance from the cross-dock facility to the factory</td>
</tr>
<tr>
<td>( f_{\text{cross,year}} )</td>
<td>Total yearly deliveries cross-dock</td>
</tr>
<tr>
<td>( V )</td>
<td>Yearly demand</td>
</tr>
<tr>
<td>( v_{\text{cross}} )</td>
<td>Cross-dock average drop size</td>
</tr>
</tbody>
</table>

Following the structure of the milk-run section, the last component that has to be discussed is the sensitivity analysis of the cross-dock model.

7.3.3 Sensitivity analysis of the cross-dock model

When considering a sensitivity analysis of the cross-dock model that will be presented in this section, two different analyses can and will be performed. The first one will be on the facility location module and assesses the impact of changing a supplier’s position on the optimal facility location. The second one will be the effect on the transport cost of multiple parameters.

When looking at the output of the facility location module, this will give both an \( x \) and \( y \)-coordinate of the cross-dock center. To described the variation in location, the distance between the new location \((x_i, y_i)\) and the standard location \((x, y)\) will be used for the sensitivity analysis and calculated by \( \sqrt{(x_i - x)^2 + (y_i - y)^2} \). In the standard scenario there will be four suppliers that deliver 24 times a year 8 pallets with the following coordinates:

- Supplier 1: 0.0
- Supplier 2: 4.0
- Supplier 3: 0.4
- Supplier 4: 4.4

For the first sensitivity analysis the properties of supplier 4 are varied, including the location (only the \( x \)-coordinate) and yearly volume (Yearly frequency · Average drop-size). This leads to figure 7.6 (see next page) and remarkably shows that locating one supplier closer to another (in this case supplier 4 moves towards supplier 3) has more impact than reducing the yearly volume. Moving one supplier further from the rest has less influence than increasing the yearly volume. Still both parameters have a significant influence and thus attention has to be paid to the determination of the parameters.
Figure 7.6: Sensitivity analysis on the cross-dock facility location

So by a variation in demand or the supplier’s location, the positioning of the cross-dock facility is influenced as well what results in different transport costs. Here again, the effect of a number of parameter on the transport cost are determined because the share of the transport cost will probably be the largest. So the effect of the following parameters is assessed:

- Distance from the suppliers to the cross-dock facility
- Distance from the cross-dock facility to the factory
- Volume supplied by one supplier
- Location of one supplier
- Transport cost from the suppliers to the cross-dock facility

For this sensitivity analysis, the same coordinates as mentioned before are used for the supplier and the factory is located at 500 kilometer from the cross-dock center. To assess different distances from the suppliers to the cross-dock facility, the conversion factor $f_\sigma$ for the grid coordinates is varied with an initial value of 50 km/grid-unit, leading to an initial distance from the suppliers to the cross-dock facility of 141 km. Other values that will be used for the sensitivity analysis are:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e$</td>
<td>Empty kilometers after unloading</td>
<td>30</td>
<td>km</td>
</tr>
<tr>
<td>$f_{cross,year}$</td>
<td>Total yearly deliveries cross-dock</td>
<td>24</td>
<td>-</td>
</tr>
<tr>
<td>$p_{docking}$</td>
<td>Cost for docking a truck</td>
<td>30</td>
<td>€</td>
</tr>
<tr>
<td>$p_{km}$</td>
<td>Transportation price per km</td>
<td>1</td>
<td>€/km</td>
</tr>
<tr>
<td>$p_{km,c}$</td>
<td>Transportation price per km from supplier to cross-dock facility</td>
<td>2</td>
<td>€/km</td>
</tr>
</tbody>
</table>

With these values and the variation of the five different parameters studied in this sensitivity analysis, it leads to the graph illustrated in figure 7.7.
Whereas the effect of varying the demand and location of a supplier was significant on the position of the cross-dock facility, the opposite is true when considering this influence on the transport cost. The most influencing parameters (from high to low) are: (1) Transport cost to the cross-dock center, (2) Distance from the suppliers to the cross-dock facility and (3) the distance from the cross-dock center to the factory. As was the case in the sensitivity analysis of the milk-run, the numbers presented do not give any clarity on the effectiveness of a cross-dock solution and the relative effect of the parameters. Since two of the five parameters presented are not really influencing the transport cost, they are not incorporated. Thus with the other three parameters, the following results are calculated that indicate the effectiveness\(^3\) in figure 7.8 on the next page.

---

\(^3\)The effectiveness is the difference in cost realized by a parameter with respect to the current situation.
From the effectiveness figure it can be concluded that cross-docking is not beneficial for a situation that matches the one used here. However, it can be seen that when the transport cost to the cross-dock facility are really low, the situation will become beneficial. So such a graph can be perfectly used to identify the minimal values for an advantageous cross-docking solution.

Because the transport cost in the current situation are comparable with the result of the value for the milk-run and therefore no further study is performed on inventory, handling and ordering cost. Though it can be stated that the handling cost will gain some importance due to the cost of cross-docking a pallet, but this will not be significant enough since this are only 576 pallets year. With a handling tariff of 3 euro per pallet this would result in €1728 extra handling cost, which is approximately 5% of the total cost.

7.4 Vendor Managed Inventory model

Developing the models in the previous two sections was relative simple because there was only data of Danone Baby Nutrition required. Also the general components could be used together with additional modules to determine the optimal route, location of the cross-dock facility and the new replenishment frequency. In case of Vendor Managed Inventory (VMI) this will be different and therefore the meaning of VMI will first be shortly stated. In a VMI arrangement the buyer transfers the responsibility of the replenishment actions to the vendor/supplier. At first sight there is no simple additional module that can be applied to calculate the effects of VMI on the selected criteria. Therefore the model for a VMI situation in a manufacturer-retailer system developed by Bookbinder et al. (2010) will be introduced and described. When this is done, it will be used to develop the VMI model incorporating the general calculation models. A sensitivity analysis will be performed in the end.

7.4.1 General formulation of the Vendor Managed Inventory model

As was already mentioned, this section will introduce and explain the model as it is presented in Bookbinder et al. (2010). Bookbinder et al. (2010) presents three different situations of which calculating the current situation and the VMI setting are relevant here. For both situations different equations are presented for the vendor/supplier and the buyer, this structure is also preserved here but in a more summarized description. So for a detailed description and considerations it is recommended to consult Bookbinder et al. (2010).

To keep the presented model feasible, it is assumed that the supplier produces more than the buyer needs per year \( p > d \). With VMI some of the costs will not shift from the buyer to the supplier, so costs related to receiving and processing of the order information and for releasing the goods are always for the supplier. The buyer will incur the costs of receiving the shipments from the supplier. Both the supplier and the buyer are responsible for their own inventory costs. This means that the VMI arrangement does not include a consignment stock agreement\(^4\).

\(^4\)In a consignment stock agreement the stock located at the buyer is still owned by the supplier up to the moment that the buyer uses the material
Before the calculations will be presented, the basic notations and equations will be introduced, starting with the buyers fixed costs of ordering $A_c$:

$$ A_c = a_o + a_t + a_r $$  \hfill (7.59)

With:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_c$</td>
<td>Buyers fixed cost per order</td>
<td>€</td>
</tr>
<tr>
<td>$a_o$</td>
<td>Cost of issuing the order</td>
<td>€</td>
</tr>
<tr>
<td>$a_t$</td>
<td>Transport costs</td>
<td>€</td>
</tr>
<tr>
<td>$a_r$</td>
<td>Cost of receiving the goods ordered</td>
<td>€</td>
</tr>
</tbody>
</table>

And the annual holding costs $h_c$:

$$ h_c = h + h_s $$  \hfill (7.60)

With:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_c$</td>
<td>Annual cost to carry one unit in stock</td>
<td>€</td>
</tr>
<tr>
<td>$h$</td>
<td>Cost of capital per item</td>
<td>€</td>
</tr>
<tr>
<td>$h_s$</td>
<td>Physical storage cost of an item</td>
<td>€</td>
</tr>
</tbody>
</table>

Furthermore the following symbols will be used to establish the VMI calculation model:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>Suppliers fixed production setup costs</td>
<td>€/setup</td>
</tr>
<tr>
<td>$a_c$</td>
<td>Suppliers costs per shipment release</td>
<td>€/shipment</td>
</tr>
<tr>
<td>$h_c$</td>
<td>Suppliers annual holding cost per unit</td>
<td>€/unit/year</td>
</tr>
<tr>
<td>$p$</td>
<td>Suppliers annual production rate</td>
<td>Units/year</td>
</tr>
<tr>
<td>$d$</td>
<td>Buyers annual demand rate</td>
<td>Units/year</td>
</tr>
<tr>
<td>$k_i$</td>
<td>Number of shipments to buyer between successive production runs</td>
<td>-</td>
</tr>
</tbody>
</table>

With this information the step can be made to calculating the buyer's total costs in the current situation.

**Current situation: Buyer**

To determine the current annual costs of the buyer, first the optimal replenishment quantity or economic order quantity (EOQ) has to be calculated by:

$$ \sqrt{\frac{2A_c d}{h_c}} = EOQ = q_1^* $$  \hfill (7.61)

This replenishment quantity is assumed to be the quantity that the buyer orders at the supplier. When this is filled in at the total cost equation $TC = 0.5 \cdot q_1^* \cdot h_c + A_c \cdot d/q_1^*$, it leads to:

$$ TC_{h_c} = \sqrt{2A_c dh_c} $$  \hfill (7.62)

From these equations it can be seen that there are four components included in calculating the total annual costs of which the first three are included in $A_c$: (1) Transport costs, (2) Order costs, (3) Handling costs and (4) Holding costs.

**Current situation: Supplier**

Also the supplier's perspective has to be included because VMI is a cooperation strategy between the supplier and the buyer. According to Bookbinder et al. (2010) the suppliers mean stock level is equal to:

$$ \frac{q_1^*}{2} + (p - d) \frac{Q_1}{2p} $$  \hfill (7.63)
In which $Q_1$ is the batch size of the supplier in the current situation and leading to the next total cost equation:

$$TC_{s1} = d(S/Q_1 + a_v/q_1^*) + 0.5 \cdot h_v[q_1^* + (1 - d/p)Q1]$$

$$= \frac{dS}{Q_1} + \frac{h_v}{2}(1 - d/p)Q1 + \frac{da_v}{q_1} + \frac{h_v q_1^2}{2}$$

(7.64)

In this formula the first part corresponds to the production setup and shipment release costs and the second part is related to the inventory carrying costs. The bold part in the equation on the second line is the part of the supplier’s total costs where it has no influence on it. This is because this is determined by the replenishment quantity $q_1^*$ selected by the buyer. In this equation the only variable that can be influence by the supplier is $Q_1$ for which the optimal quantity in one cycle (Economic Production Quantity, EPQ) is determined by:

$$Q_1^* = \sqrt{\frac{2Sd}{h_v(1 - d/p)}} = EPQ$$

(7.65)

Based on the equations presented for $q_1^*$ and $Q_1^*$ the total cost equation can be rewritten to:

$$TC_{s1}^{*} = \sqrt{2Sdh_v(1 - d/p)} + \frac{da_v}{\sqrt{2A_c d/ h_c}} + 0.5 \cdot h_v \sqrt{2A_c d/ h_c}$$

(7.66)

This was the last equation of the current situation so that now the VMI situation can be introduced.

**Vendor Managed Inventory: Buyer**

In a VMI arrangement, the buyer is no longer responsible for placing orders and thus does not pays orderings costs $a_o$. However the inventory holding costs and the transport costs are still paid by the buyer. As a result of the fact that the supplier determines the replenishment quantity, the supplier also influences the holding cost of the buyer. In the next subparagraph the equation for this new replenishment quantity $q_2^*$ will be presented, but for now this leads to the following total equation for the buyer:

$$TC_{b2} = 0.5 \cdot q_2^* \cdot h_c + (a_t + a_v) \cdot d/q_2^*$$

(7.67)

And with equation 7.71 for $q_2^*$ this results in:

$$TC_{b2} = 0.5 \cdot h_c \cdot q_2^* \sqrt{\frac{2(a_v + \beta_1 a_o)d}{h_v}} + \frac{(a_t + a_v) \cdot d}{2(a_v + \beta_1 a_o) h_v}$$

(7.68)

**Vendor Managed Inventory: Supplier**

Whereas in the current situation the supplier was only partly in control of the incurred costs, he is now able to influence all costs. The supplier will also have an extra cost component related to issuing an order, for which it is assumed that the costs for the supplier are equal to $\beta_1 a_o$. In this case $\beta_1$ can be interpreted as the suppliers efficiency factor in issuing orders (0 ≤ $\beta_1$ ≤ 1). So the total costs of the supplier under VMI are:

$$TC_{s2} = \frac{d}{Q_2} [S + k_2(a_v + \beta_1 a_o)] + 0.5 \cdot h_v[q_2 + (1 - d/p)Q2]$$

$$= \frac{dS}{Q_2} + \frac{h_v(1 - d/p)Q2}{2} + \frac{d(a_v + \beta_1 a_o)}{q_2} + \frac{h_v q_2}{2}$$

(7.69)

In the second line $k_2$ is replaced by $Q_2/q_2$ and rewritten to obtain the displayed result. Both $f(Q_2)$ and $f(q_2)$ can be individually optimized by finding the optimal values for $Q_2$ and $q_2$. 
The optimal value for \( f(Q_2) \) occurs when:

\[
Q^*_2 = \sqrt{\frac{2Sd}{h_v(1 - d/p)}}
\]  

(7.70)

Whereas the optimal value for \( f(q_2) \) under VMI is:

\[
q^*_2 = \sqrt{\frac{2(a_v + \beta_1 a_o)d}{h_v}}
\]  

(7.71)

All equations presented here can be used to determine the values for \( TC_{b2} \) and \( TC_{s2} \). Now these equations are adapted to be in line with the general equations in this research report so that the VMI concept can be compared with the other ones.

### 7.4.2 Adapting the VMI model of Bookbinder

In this paragraph the VMI model of Bookbinder et al. (2010) is adapted to justify a comparison with the other concepts. This will be done by substituting the general calculation models in the VMI model presented by Bookbinder et al. (2010), thereby leading to a VMI model that can be used in the inbound logistic decision support model. The focus will be on substituting the general calculation models in the equations to determine the costs for the buyer, Danone Baby Nutrition. Before the model is adapted, the symbols used by Bookbinder et al. (2010) and presented in the previous paragraph are converted into the symbols used in this report. This overview of the symbols used here and the corresponding symbols of Bookbinder et al. (2010) can be found in table 7.10.

<table>
<thead>
<tr>
<th>Symbol Bookbinder</th>
<th>Symbol Report</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a_o )</td>
<td>( p_{order} )</td>
<td>Ordering costs</td>
</tr>
<tr>
<td>( a_v )</td>
<td>( p_{release} )</td>
<td>Supplier’s cost per shipment release</td>
</tr>
<tr>
<td>( h_v )</td>
<td>( h_{supplier} )</td>
<td>Supplier’s holding cost per unit</td>
</tr>
<tr>
<td>( S )</td>
<td>( S )</td>
<td>Supplier’s production setup cost</td>
</tr>
<tr>
<td>( p )</td>
<td>( p )</td>
<td>Supplier’s annual production rate</td>
</tr>
<tr>
<td>( q^*_1 )</td>
<td>( v_c )</td>
<td>Current replenishment quantity</td>
</tr>
<tr>
<td>( q^*_2 )</td>
<td>( q_{vmi} )</td>
<td>Optimal replenishment quantity under VMI</td>
</tr>
<tr>
<td>( Q^*_1 )</td>
<td>( Q_c )</td>
<td>Current optimal production quantity</td>
</tr>
<tr>
<td>( Q^*_2 )</td>
<td>( Q_{vmi} )</td>
<td>Optimal production quantity under VMI</td>
</tr>
</tbody>
</table>

Besides the conversion of the symbols used by Bookbinder et al. (2010), also the symbols used in this report will get an extra addition when the symbol can be used for the supplier as well. This addition will be \( S \). For example the storage cost per pallet for the supplier will be \( p_{store,S} \) whereas this is \( p_{store} \) for the buyer. With this note on symbols, the model of Bookbinder et al. (2010) can be adapted.

**Adapted current situation model for Danone Baby Nutrition**

The first component of the model presented by Bookbinder et al. (2010) was describing the current situation of the buyer which is Danone Baby Nutrition in this case. This means that the general calculation models can replace this complete component since the model of Bookbinder et al.
(2010) assumed that the buyer is ordering the economic order quantity whereas the real order quantities of Danone Baby Nutrition are known. So therefore the equations and steps presented in section 7.1 can be used. Thus also the invested amount of capital will be calculated, what was not the case in the model of Bookbinder et al. (2010).

**Adapted current situation model for the supplier**

At first instance there is no data available of the supplier and its variables, so both the current and VMI situation models are based on assumptions for the following values:

- Production setup costs $S$;
- Annual production rate $p$;
- Annual holding costs of a unit $h_{\text{supplier}}$;
- Cost per shipment release $p_{\text{release}}$.

However some of these values, especially the production setup costs $S$ and the annual production rate $p$ can be estimated by employees of the buying company.

Besides these specific values, the order quantity $q^*_c$ will be replaced by the actual replenishment quantity ordered in the current situation $v_c$, which is in line with the symbol conversion, and the annual demand can also be replaced by the actual demand $V = f_{\text{c,year}} \cdot v_c$. Also the holding costs $h_{\text{supplier}}$ can be replaced by $(\bar{v}_{\text{pallet}} \cdot p_{\text{carrying},S} + p_{\text{store},S})$ to include both the physical storage as the cost of capital for the inventory. This enables the researcher to rewrite the equation to calculate the total costs for the supplier in the current situation. This is not done directly because also for the supplier the same structure will be maintained as for Danone Baby Nutrition, thereby creating separate equations for different components. It should be realized that the supplier is not paying handling and transportation costs but is paying costs for setting-up and dispatching the order. The supplier also pays ordering costs that are transferred from the buyer to the supplier under VMI. Finally this leads to the following equations:

- **Inventory costs**

  \[
  C_{\text{inventory},S} = \frac{\bar{v}_{\text{pallet}} \cdot p_{\text{carrying},S} + p_{\text{store},S}}{2} \left[ v_c + \left( 1 - \frac{f_{\text{c,year}} \cdot v_c}{p} \right) Q_c \right] \quad (7.72)
  \]

- **Production and shipment release costs**

  \[
  C_{\text{release},S} = f_{\text{c,year}} \cdot v_c \left( \frac{S}{Q_c} + \frac{p_{\text{release}}}{v_c} \right) \quad (7.73)
  \]

- **Ordering costs**

  \[
  C_{\text{order},S} = 0 \quad (7.74)
  \]

- **Capital model**

  \[
  G_S = \bar{v}_{\text{pallet}} \left[ v_c + \left( 1 - \frac{f_{\text{c,year}} \cdot v_c}{p} \right) Q_c \right] \quad (7.75)
  \]

In all these equations the next formula is valid for $Q_c$:

\[
Q_c = \sqrt{\frac{2S \cdot v_c \cdot f_{\text{c,year}}}{\left( \bar{v}_{\text{pallet}} \cdot p_{\text{carrying},S} + p_{\text{store},S} \right) \left( 1 - \frac{f_{\text{c,year}} \cdot v_c}{p} \right)}} \quad (7.76)
\]

Now the calculation of the VMI model can be presented.
Cost of the supplier under VMI

The principle difference between the current situation and a possible VMI situation is that the supplier determines the replenishment quantity and also incurs the ordering costs instead of the buyer. So therefore it is chosen to first adapt the model of the supplier for the VMI situation. In this case the most important difference is the new replenishment quantity. This new quantity can be calculated by:

\[ q_{vmi} = \sqrt{\frac{2(\text{prelease} + \beta \text{Porder}) f_{c,year} \cdot v_c}{v_{\text{pallet}} \cdot \text{Pcarrying},S + p_{\text{store}},S}} \]  

(7.77)

Besides this new replenishment quantity, the production quantity has to be determined as well, but this is equal to the economic production quantity of the current situation and thus leads to:

\[ Q_{vmi} = Q_c = \sqrt{\frac{2S \cdot v_c \cdot f_{c,year}}{(v_{\text{pallet}} \cdot \text{Pcarrying},S + p_{\text{store}},S)(1 - \frac{f_{c,year} \cdot v_c}{p})}} \]  

(7.78)

With these two equations for \( q_{vmi} \) and \( Q_{vmi} \) the formulas can be established to calculate the total costs for the supplier in a Vendor Managed Inventory situation:

- **Inventory costs**
  \[ C_{VMl,\text{inventory},S} = \frac{(v_{\text{pallet}} \cdot \text{Pcarrying},S + p_{\text{store}},S)}{2} \left[ q_{vmi} + \left( 1 - \frac{f_{c,year} \cdot v_c}{p} \right) Q_{vmi} \right] \]  

(7.79)

- **Production and shipment release costs**
  \[ C_{VMl,\text{release},S} = f_{c,year} \cdot v_c \left( \frac{S}{Q_{vmi}} + \frac{\text{prelease}}{q_{vmi}} \right) \]  

(7.80)

- **Ordering costs**
  - In this equation \( \beta \) is the efficiency factor in ordering of the supplier
  \[ C_{VMl,\text{order},S} = \beta \text{Porder} \frac{f_{c,year} \cdot v_c}{q_{vmi}} \]  

(7.81)

- **Invested capital model**
  \[ G_{VMl,S} = \frac{v_{\text{pallet}}}{2} \left[ q_{vmi} + \left( 1 - \frac{f_{c,year} \cdot v_c}{p} \right) Q_{vmi} \right] \]  

(7.82)

And by summing up all components, except the invested capital, the total costs \( TC_{S2} \) is obtained. So now the last component of the VMI calculation model can be described, the total costs of Danone Baby Nutrition under VMI.

** Buyers cost under VMI**

By transferring the costs of ordering to the supplier, thereby reducing this component to zero for the buyer, only four components remain: (1) transport costs, (2) inventory costs, (3) handling costs and (4) invested capital. Each of these four components are dependent on the replenishment quantity \( q_{vmi} \) that is now set by the supplier.
To calculate these new costs under VMI, each equation has to be adapted with this new replenishment quantity. When this is done it results in:

- **Transport costs**

\[
C_{VMI,\text{transport},B} = \left( p_{km} \left[ \left[ \frac{q_{vmi}}{v_{FTL}}, 1 \right] \cdot d_{if} + (1 + L)e \right] + 2 \cdot p_{docking} \right) \cdot \frac{f_{c,\text{year}} \cdot v_{c}}{q_{vmi}} \tag{7.83}
\]

With \( L = \begin{cases} 
1 & \text{if shipment is LTL} (< v_{FTL}) \\
0 & \text{if shipment is FTL} \geq v_{FTL}
\end{cases} \)

- **Inventory costs**

\[
C_{VMI,\text{inventory},B} = \frac{q_{vmi} \cdot \left[ t_{qc}, t_{o} \right] + 0.5 \cdot q_{vmi} \cdot t_{p} \cdot q_{vmi} / v_{c}}{t_{p} \cdot q_{vmi} / v_{c} + \left[ 0, t_{qc} - t_{o} \right]} \cdot \left( \bar{v}_{\text{pallet}} \cdot p_{\text{carrying}} + p_{\text{store}} \right) \tag{7.84}
\]

- **Handling costs**

\[
C_{VMI,\text{handling},B} = \frac{\left( f_{c,\text{year}} \cdot v_{c} / q_{vmi} \right) \cdot t_{\text{check}}}{60} \cdot S_{h} + \frac{f_{c,\text{year}} \cdot v_{c} \cdot t_{\text{unload}}}{60} \cdot S_{h} \tag{7.85}
\]

- **Capital**

\[
G_{VMI,B} = \frac{q_{vmi} \cdot \left[ t_{qc}, t_{o} \right]}{t_{p} \cdot q_{vmi} / v_{c} + \left[ 0, t_{qc} - t_{o} \right]} \cdot \bar{v}_{\text{pallet}} \tag{7.86}
\]

The total costs of the buyer under VMI can be calculated by:

\[
TC_{b2} = C_{VMI,\text{transport},B} + C_{VMI,\text{inventory},B} + C_{VMI,\text{handling},B} \tag{7.87}
\]

Based on all equations presented here, a model can be constructed in Microsoft Excel to calculate the difference in costs between the current situation and the VMI scenario for both the supplier and the buyer. In the next subparagraph three possible outcomes are identified and explained.

**Type of results of a Vendor Managed Inventory scenario**

According to Bookbinder et al. (2010) the next cost savings can be identified:

1. \( TC_{s2} < TC_{s1} \): Cost savings for the supplier
2. \( TC_{b2} < TC_{b1} \): Cost savings for the buyer
3. \( TC_{s2} + TC_{b2} < TC_{s1} + TC_{b1} \): System-wide cost savings

The cost savings can be categorized in the following systems:

- When both the supplier and the buyer obtain savings (thus (1) and (2) hold), VMI is an **efficient system**;
- Either the supplier or the buyer obtains savings by VMI (so (1) or (2) holds), in this case it is a **potential efficient system**;
- An **inefficient system** is obtained when none of the parties obtain savings and thus none of the savings mentioned above are valid.
7.4.3 Flowchart of the VMI calculation model

As could be seen in this section on Vendor Managed Inventory, both the supplier and the buyer are relevant for the model, thereby making the flowchart model elaborate. Whereas there is no relation between them in the current situation, the opposite is true in a VMI agreement. Since there is no connection between the supplier and the buyer, there is no flowchart created for the current situation, only for the VMI situation. This flowchart can be seen in figure 7.9.

![Flowchart of the VMI calculation model](image)

Figure 7.9: Flowchart of the Vendor Managed Inventory performance assessment model

In this flowchart the following symbols are used:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>Order efficiency factor</td>
</tr>
<tr>
<td>$f_{c,year}$</td>
<td>Current total deliveries per year</td>
</tr>
<tr>
<td>$h_{supplier}$</td>
<td>Suppliers annual holding per item</td>
</tr>
<tr>
<td>$p$</td>
<td>Annual production capacity</td>
</tr>
<tr>
<td>$P_{release}$</td>
<td>Cost per shipment release</td>
</tr>
<tr>
<td>$P_{store,S}$</td>
<td>Annual cost of physical storage per item</td>
</tr>
<tr>
<td>$P_{carrying,S}$</td>
<td>Annual carrying cost per euro of inventory per year</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>Production setup costs</td>
</tr>
<tr>
<td>$t_{qc}$</td>
<td>Duration quality check</td>
</tr>
<tr>
<td>$t_o$</td>
<td>Overlap</td>
</tr>
<tr>
<td>$U$</td>
<td>Product utilization</td>
</tr>
<tr>
<td>$v_c$</td>
<td>Current average drop size</td>
</tr>
<tr>
<td>$\bar{v}_{pallet}$</td>
<td>Average pallet value</td>
</tr>
</tbody>
</table>

Table 7.11: Supplier related input symbols of the VMI flowchart

93
As was also done in for the milk-run and cross-dock models, a sensitivity analysis is performed in the next paragraph.

### 7.4.4 VMI sensitivity analysis

The last two sensitivity analyses were focussing on the transport costs since this is the most dominant cost component and because only the buyer, which is in this case Danone Baby Nutrition, was involved. With Vendor Managed Inventory not only the buyer but also the supplier is affecting the cost components and thus the success of the concept. So using the same setup for the sensitivity analysis here will not be useful and therefore a different approach should be used.

When comparing the equations used to calculate the costs for the buyer in the current situation and under VMI, it is found that they are equal to each other but then adapted for a different delivery quantity \( Q_{vmi} \) under VMI. This is also valid for the supplier because it holds that \( Q_c = Q_{vmi} \). In both cases the ordering costs are either excluded (buyer) or introduced (supplier) in the VMI scenario, however it is still assumed that the ordering cost is not the most important component and will thus not be considered in this analysis.

The approach taken in this sensitivity analysis is to split it up into three parts, one for the effects on \( q_{vmi} \) and \( Q_{vmi} \), one for the suppliers equations and one for the buyers formulas. The sensitivity analysis is presented in this order.

**Effect on \( q_{vmi} \) and \( Q_{vmi} \)**

As was mentioned \( q_{vmi} \) and \( Q_{vmi} \) are the parameters that are causing the main difference in a Vendor Managed Inventory arrangement compared to the current situation. So in this subparagraph a sensitivity analysis is performed to assess the influence of various parameters on \( q_{vmi} \) and \( Q_{vmi} \).

For this sensitivity analysis it is chosen to use a supplier that delivers 8 pallets twice a month and produces 2500 pallets a year. So that the importance of the buyer is high (7.68% of the total volume produced by the supplier). And it is assured that \( q_{pallet} \cdot P_{carrying,S} \neq P_{store,S} \). Incorporating this in the analysis leads to figures 7.10a and 7.10b for \( q_{vmi} \) and \( Q_{vmi} \) on the next page. The parameter values that are used here can be found in appendix E.

Let’s first consider the shipping quantity \( q_{vmi} \), when looking at figure 7.10a it can be seen that when reducing the parameter values, the most influential one is the yearly volume that leads to a reduction of the shipment quantity \( q_{vmi} \). When reducing the cost of capital or the physical storage

---

### Table 7.12: General input symbols of the VMI flowchart

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e )</td>
<td>Empty kilometers after unloading</td>
</tr>
<tr>
<td>( P_{carrying} )</td>
<td>Carrying cost per euro of inventory per year</td>
</tr>
<tr>
<td>( P_{docking} )</td>
<td>Cost for docking a truck</td>
</tr>
<tr>
<td>( P_{km} )</td>
<td>Transportation price per km</td>
</tr>
<tr>
<td>( P_{order} )</td>
<td>Ordering cost per order</td>
</tr>
<tr>
<td>( P_{store} )</td>
<td>Annual cost of physical storage per item</td>
</tr>
<tr>
<td>( t_{check} )</td>
<td>Time required to check a truck and transport documents</td>
</tr>
<tr>
<td>( t_{unload} )</td>
<td>Time required to unload, check, label and store incoming pallets</td>
</tr>
<tr>
<td>( S_h )</td>
<td>Hourly salary of an inbound warehouse employee</td>
</tr>
</tbody>
</table>
cost, the shipment quantity is increased and thus has an inverted effect. It is difficult to see in the figure, but the ordering cost and order efficiency are equally important.

Figure 7.10: Sensitivity analysis of $q_{vmi}$ on $Q_{vmi}$

Also for the optimal production quantity $Q_{vmi}$ holds that the yearly volume fulfils an important role, closely followed by the setup cost. However when the yearly volume produced by the supplier, represented by the line of the total production volume, approaches the yearly quantity ordered by the buyer, this production volume gains importance rapidly. This means that when the buyer, Danone Baby Nutrition, is expected to be responsible for more than half of the suppliers sales, this number should be evaluated closely.

From now on $q_{vmi}$ and $Q_{vmi}$ are seen as numbers and thereby the relationship with the replenishment quantity and frequency is neglected for reasons of simplicity, thereby making it possible to independently vary $q_{vmi}, Q_{vmi}, v_c$ and $f_{c,\text{year}}$.

Supplier

The equations used to calculate the suppliers cost are included in the sensitivity analysis as well and are evaluated in this subparagraph, focussing on the inventory and production and shipment release costs. In this case only one analysis will be performed since the difference between the current and the VMI situation is only the value of $v_c/q_{vmi}$.

Figure 7.11: Sensitivity analysis of the supplier
When considering the results of the sensitivity analysis on the suppliers inventory cost displayed in figure 7.11a, it can be clearly seen that carrying cost (cost of capital) is the most important parameter and thus also the pallet value of which the line is behind the one of the carrying cost.

The second part of the suppliers analysis is on the production and shipment release costs and resulted in figure 7.11b. As could be expected from the equation, the shipment frequency is in general the most important factor. However when the production size is rather low this will be the most dominant parameter (production size) that determines the production and shipment release cost. This is the only non-linear and inverted relation between the input and output.

It should be noted that the inventory cost is more or less equal to the production and shipment release cost. And thus the most important parameter will be the shipment frequency because this is the most important one overall. The last part of the sensitivity analysis will be on the buyer in the next subparagraph.

**Buyer**

When taking a closer look at the equations presented to calculate the cost components for the buyer, they are similar to the equations for the current situation presented in section 7.1. The only difference is the correction to the new delivery quantity and frequency under VMI. So for the transportation cost, the results from the sensitivity analysis conducted in paragraph 6.7.1 are also valid here.

The sensitivity analysis performed on the inventory costs in paragraph 6.7.2 did not contain a correction for a different volume that also leads to a new time needed to consume the supplied amount during production. This correction can be recognized in the equations by $q_{vmi}/v_c$ and will be the only component included here. However this is equals a variation in the time to consume the quantity delivered per replenishment action ($t_p$) and thus also here is referred to the previously performed analysis in paragraph 6.7.2.

In these analyses it was discovered that for the transportation cost function the number of deliveries per year ($f_{c,year}$), the transport price ($p_{km}$) and the distance to the factory ($d_{lf}$) are most important. For the inventory costs this are $t_p$ and $v_c$ are most important.

With this obtained information, the last concept assessment model on Just-in-Time delivery can be developed in the next section.

### 7.5 Just-in-Time delivery model

In the most ideal situation of Just-in-Time delivery (JIT), each product that is required for production is delivered when it is needed. This will lead to a zero inventory situation and thereby reduces the related inventory costs and invested capital to zero. However, this is in the most ideal situation from a JIT perspective and lacks the perspective of transport costs that will significantly increase because the products have to be shipped piece by piece.

Before the calculation model is presented, it should be realized that JIT delivery can be applied on different levels, either seen from the packaging perspective or from the demand perspective. When considering the packaging levels, this will be (Hellström and Saghir, 2007; Vernuccio and Cozzolino, 2010):

- Primary level: On product level
- Secondary level: On box level
- Tertiary level: On pallet level
- On truck level
Whereas different demand levels are classified as follows by the researcher:

- Hourly demand level
- Daily demand level
- Weekly demand level
- Monthly demand level
- Yearly demand level

When a volume equal to the yearly demand is delivered, this is under normal circumstance not a JIT delivery\(^5\) since the objective of the JIT concept is to eliminate inventory costs. Therefore the levels of the weekly, monthly and yearly demand will no longer be considered here.

It is not considered to be likely that the inbound goods are shipped on product level because this will result in tremendous transportation costs. Shipping on product level is feasible when the supplier and buyer are producing wall to wall and have a conveyor belt for transportation. So also this level will be excluded as well as the truck level, because this is the largest quantity that can be shipped in one time and will thus be already used when this is needed to fulfil the demand. Also shipping per box is assumed to be not relevant in the day to day practice of a manufacturing company since this will only be used for very slow moving products, highly perishable products and products for which the demand period is very small. So in the end, the products are supplied on pallet level and fulfil the hourly demand or a multiple hour demand up to the daily demand.

The essential difference between the current situation and a JIT situation is the delivery frequency. So therefore the number of delivery frequencies will defined here that will be used as input for the JIT calculation model. The frequencies \( f_{\text{JIT}} \) that the researcher thinks to be suitable are:

<table>
<thead>
<tr>
<th>Level</th>
<th>Deliveries per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily production demand</td>
<td>1</td>
</tr>
<tr>
<td>Half a production day demand</td>
<td>2</td>
</tr>
<tr>
<td>Quarter of a production day demand</td>
<td>4</td>
</tr>
<tr>
<td>Hourly production demand</td>
<td>( t_{\text{day}} )</td>
</tr>
</tbody>
</table>

Note that the number of deliveries per day to fulfil the hourly demand is dependent on the number of working hours in one day \( t_{\text{day}} \). Thereby the frequency will be kept as input for the calculation model so that this can always be adapted by the user. The new delivery quantity is calculated by:

\[
\frac{f_{\text{JIT, year}}}{f_{\text{JIT, year}}} \cdot v_c = \frac{f_{\text{JIT, year}}}{365} \cdot v_c
\]

So to calculate the effect of a JIT delivery, the frequency will be varied and thus no separate module is needed in addition to the five general modules. Though the most optimal frequency has to be selected of these five frequencies and this will be done by selecting the one with the lowest total costs. This is done because when this is done from an invested capital perspective will always be the delivery rate that fulfils the hourly demand because this leads to a lower stock level compared to the other four frequencies.

Each of the five general components will now be adapted so that they included the varying JIT delivery frequency \( f_{\text{JIT}} \).

\(^5\) In the exceptional case that a product is only needed one day a year, this delivery can be considered JIT.
7.5.1 JIT transport costs

When considering the transport costs of a JIT situation, there are two changes that have to be incorporated in the model:

1. The yearly frequency \( f_{JIT,\text{year}} \) will be equal to \( f_{JIT} \cdot 365 \) and varies linearly with \( f_{JIT} \);
2. Since JIT suppliers are having a high probability of being located close to the factory, a different transport rate per kilometer is valid: \( p_{km,JIT} \).

Using these two changes in the general transport model, it will lead to:

\[
C_{JIT,\text{transport}} = (p_{km,JIT} \left[ \frac{v_{JIT}}{v_{FTL}}, 1 \right] \cdot d_{if} + (1 + L)e) \cdot f_{JIT} \cdot 365
\]

In which \( L \) will be equal to 1 if the shipment is a full truckload and 0 otherwise. Despite the fact that the chance is rather small that a JIT scenario included full truckloads, parameter \( L \) will not be excluded.

7.5.2 JIT inventory costs

A new delivery frequency will lead to a lower inventory level which is the main goal of a JIT delivery strategy. But when looking at the general equation used to determine the inventory costs (see equation below), it can be seen that there is time included for the duration of a quality check in days. This quality control can be the bottleneck when a company tries to lower the inventory costs by increasing the replenishment frequency. However, it will still be included whereas it can be excluded as well when this is desirable by setting its value on zero.

\[
C_{\text{inventory}} = U \cdot \frac{Q \cdot [t_{qc}, t_o] + \frac{Q}{t} t_p}{t_p + [0, t_{qc} - t_o]} \cdot (v_{\text{pallet}} \cdot p_{\text{carrying}} + p_{\text{store}})
\]

As was the case at all other three concepts also here the inventory cost function has to be adapted to the new replenishment quantity and the related production time to consume this quantity. This results in:

\[
C_{\text{inventory,JIT}} = U_i \cdot \frac{v_{JIT} \cdot [t_{qc}, t_o] + 0.5 \cdot v_{JIT} \cdot t_p \cdot v_{JIT}/v_c}{t_p \cdot v_{JIT}/v_c + [0, t_{qc} - t_o]} \cdot (v_{\text{pallet}} \cdot p_{\text{carrying}} + p_{\text{store}})
\]

7.5.3 JIT handling costs

The handling cost in a JIT scenario are also influenced by the increased number of trucks that have to be unloaded at the factory. So when the general handling cost equation is being adapted, as it was also done for the other concepts, this leads to:

\[
C_{\text{handling,JIT}} = \frac{365 \cdot f_{JIT} \cdot t_{\text{check}}}{60} \cdot S_h + \frac{t_{\text{unload}} \cdot V}{60} \cdot S_h
\]

7.5.4 JIT ordering costs

The approach used to calculate the ordering costs will be different here compared to the other concepts, because the researcher has the opinion that there is a rather large possibility that the buyer and the supplier make an arrangement in which the buyer places one order at the supplier that contains multiple individual deliveries. Therefore the number of shipments per order, \( n_{\text{ship/order}} \) is introduced that states the number of shipments are present per order placed.
Combining this with the standard equation for the ordering costs $n_{\text{order}} \cdot P_{\text{order}}$, will lead to the following equation of the total annual ordering costs under JIT:

$$C_{\text{order,JIT}} = \frac{365 \cdot f_{\text{JIT}}}{n_{\text{ship/order}} \cdot P_{\text{order}}} \quad (7.94)$$

When every order contains only one shipment this equation will be equal to the standard equation for the ordering costs adapted to the number of orders in a JIT situation.

### 7.5.5 JIT invested capital

The last general component that has to be adapted to the JIT situation is the amount of invested capital in the inventory. The equation of the inventory cost component can be used in which the average inventory part of this equation is multiplied by the average pallet value $v_{\text{pallet}}$, resulting in:

$$G_{\text{JIT}} = U_i \cdot \left[ v_{\text{JIT}} \cdot \left[ t_{qc} - t_o \right] + 0.5 \cdot v_{\text{JIT}} \cdot t_p \cdot \frac{v_{\text{JIT}}}{v_c} \cdot \frac{t_p}{v_{\text{pallet}}} \right] + [0, t_{qc} - t_o]$$

$$\left(7.95\right)$$

With this last equation all formulas of the JIT model have been presented so that now the flowchart can be constructed.

### 7.5.6 Flowchart of the JIT delivery model

Despite the simplicity of the JIT model in which only the delivery frequency is increased, thereby reducing the inventory levels, a flowchart will be presented in the paragraph with corresponding symbol descriptions.

![Flowchart of the JIT delivery model](image)

Figure 7.12: Flowchart of the Just-in-Time delivery performance assessment model
7.5.7 Sensitivity analysis

The last component of this section and chapter is the sensitivity analysis of the Just-in-Time delivery model. As was already shown in paragraph 6.7.6, the most important cost component is the transport cost. The relative importance of the transport costs in a Just-in-Time delivery model will only be larger due to the higher number of deliveries and the attempt to eliminate inventory. So also in this last sensitivity analysis the focus will be on the transport cost function. Despite that this analysis will be similar with the one presented in paragraph 6.7.1, it will be performed again. Now this is done with a different delivery frequency of which the initial value will be twice a day (730 deliveries per year). The price per kilometer is adjusted as well to 2.00 €/km due to the shorter distance between the supplier and the factory of 100 km. Other parameter values used can be found in appendix E. In the end this results in figure 7.13 on the next page and shows that the replenishment frequency is the most important parameter, followed by the price per kilometer and the empty kilometers to the next pick-up location. All other parameters are equally important, but less important compared to the top three parameters mentioned. Due to the different values used compared to the analysis in paragraph 6.7.1, a different figure is presented in which the lines are not so close to each other.
Figure 7.13: Transport cost sensitivity analysis of the Just-in-Time delivery model

With this last sensitivity analysis the chapter on the calculation models for concept performance assessment is finalized so that now the inbound logistic decision support model can be constructed and presented in the next chapter.
Chapter 8

Building and evaluating the inbound logistic decision support model

For each of the four concepts, the corresponding calculation models have been developed in the previous chapter with respect to the criteria presented in chapter 5. With the equations of these calculation models, a complete inbound logistic decision support model is constructed in Microsoft Excel. This software package is chosen for maximum compatibility with the available software packages at Danone Baby Nutrition as was already mentioned at the scoping in chapter 2. This chapter will contain more information on how this model is constructed and visualizes the user interface of the model. First the structure of the model constructed in Excel is presented, followed by the interface and an evaluation of the model by means of looking at the area of application and limitations of the model.

8.1 Structure of the inbound logistic decision support model

In chapter 5 the overall process of the inbound logistic decision support model was already described, so this section will focus on a flowchart of the inbound logistic decision support model that is constructed in Excel. This flowchart is presented in figure 8.1 and shows the simplistic structure.

![Flowchart of the Excel model structure](image-url)
Using the inbound logistic decision support model starts with the input of the required data on the input worksheet. This worksheet contains a table for the general input parameters, multiple tables for concept specific input data that is arranged per concept and a table for the current situation. For the input it was decided by the researcher that the model has to be able to include three supplier-concept-combinations (SCC's) for each of the four concepts (this was mentioned at the end of chapter 5). So this leads to a total of 14 input tables.

So for each concept up to three SCC's can be included in the model and for each of these SCC's a separate worksheet is created that includes the calculation models developed in the previous chapter. The data required for the calculations performed on these worksheets is directly extracted from the input worksheet. The output of all these calculation worksheets is extracted to the output worksheet.

On the output worksheet detailed information is presented on the new conditions of the SCC's, examples are a new delivery frequencies, drop-sizes, routes and locations of cross-dock facilities, the effects of these SCC's on the total costs, the four cost components and the invested capital. The results on total cost and invested capital are automatically copied to the final worksheet of the inbound decision support model to enable a ranking of the SCC's. This ranking can be based on both the absolute and relative difference between the current and future situation on either the total costs or invested capital.

With this description it is clear how the model works on a high level so that now the interface can be depicted.

8.2 User interface of the decision support model

To have a better idea about how the inbound logistic decision support model looks, the three worksheets that are important for the user are presented in this section. Besides the fact that these model illustrations give an impression of the interface, it also gives a clear overview of which parameters have to be gathered and filled in. When opening the Excel-file, the user directly sees the table for the general input parameters as visualized in figure 8.2. All information in this table has to be filled in to guarantee that the decision support model works correctly.

**Figure 8.2: Inbound logistics decision support model: General input parameters**

When the user scrolls down, the input tables for the milk-run related SCC's become visible. All three milk-run tables look like the one depicted in figure 8.3 on the next page. In this table, only the grey cells have are obligatory to fill in, whereas the white ones are optional since they
are either calculated based on the information filled in (production time $t_p$) or already contain standard values.

### MILK-RUN INPUT

#### Milk-run cluster 1

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{1g}$</td>
<td>5</td>
<td>km/coordinate</td>
<td>Distance traveled over one grid coordinate (from [0,0] to [0,1])</td>
</tr>
<tr>
<td>$t_{m}$</td>
<td>30</td>
<td>minute</td>
<td>Time needed to arrange a milk-run</td>
</tr>
<tr>
<td>$v_{sync}$</td>
<td>28</td>
<td>pallets/truck</td>
<td>Number of pallets that fit in a truck for the synchronization (recommended: 28 pallets)</td>
</tr>
</tbody>
</table>

#### Factory location

<table>
<thead>
<tr>
<th>Supplier name</th>
<th>x</th>
<th>y</th>
<th>$f_{c,y}$</th>
<th>$v_{c}$</th>
<th>$U$</th>
<th>$v_{pallet}$</th>
<th>$t_{p}$</th>
<th>$t_{q}$</th>
<th>$t_{o}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>7</td>
<td>9</td>
<td>15</td>
<td>48</td>
<td>12</td>
<td>1000</td>
<td>7.604167</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier B</td>
<td>60</td>
<td>48</td>
<td>12</td>
<td>12</td>
<td>24</td>
<td>1000</td>
<td>30.41667</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier C</td>
<td>61</td>
<td>12</td>
<td>14</td>
<td>12</td>
<td>23</td>
<td>1000</td>
<td>30.41667</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier D</td>
<td>54</td>
<td>7</td>
<td>2</td>
<td>52</td>
<td>30</td>
<td>1000</td>
<td>7.019231</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier E</td>
<td>1</td>
<td>1</td>
<td>1000</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier F</td>
<td>1</td>
<td>1</td>
<td>1000</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.3: Inbound logistics decision support model: Milk-run input parameters

After the milk-run, the same kind of tables follows for the cross-docking SCC’s. What has to be filled in obligatory and what is optional is the same as was the case for the milk-run: grey cells are obligatory and white cells are optional.

### CROSS-DOCK INPUT

#### Cross-dock cluster 1

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{c,x}$</td>
<td>9.6</td>
<td>km/coordinate</td>
<td>Distance traveled over one grid coordinate (from [0,0] to [0,1])</td>
</tr>
<tr>
<td>$c_{km,c}$</td>
<td>2</td>
<td>euro/km</td>
<td>Transportation price per km for transport from the supplier to the cross-dock facility</td>
</tr>
<tr>
<td>$t_{cross}$</td>
<td>15</td>
<td>minute</td>
<td>Time needed to arrange a cross-dock</td>
</tr>
<tr>
<td>$v_{sync}$</td>
<td>28</td>
<td>pallets/truck</td>
<td>Number of pallets that fit in a truck for the synchronization (recommended: 28 pallets)</td>
</tr>
</tbody>
</table>

#### Factory location

<table>
<thead>
<tr>
<th>Supplier name</th>
<th>x</th>
<th>y</th>
<th>$f_{c,y}$</th>
<th>$v_{c}$</th>
<th>$U$</th>
<th>$v_{pallet}$</th>
<th>$t_{p}$</th>
<th>$t_{q}$</th>
<th>$t_{o}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>6</td>
<td>13</td>
<td>12</td>
<td>48</td>
<td>8</td>
<td>1000</td>
<td>7.604167</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier B</td>
<td>8</td>
<td>8</td>
<td>16</td>
<td>48</td>
<td>1</td>
<td>1000</td>
<td>7.604167</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier C</td>
<td>11</td>
<td>7</td>
<td>15</td>
<td>12</td>
<td>12</td>
<td>1000</td>
<td>30.41667</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier D</td>
<td>17</td>
<td>8</td>
<td>20</td>
<td>12</td>
<td>4</td>
<td>1000</td>
<td>30.41667</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier E</td>
<td>35</td>
<td>12</td>
<td>11</td>
<td>52</td>
<td>10</td>
<td>1000</td>
<td>7.019231</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier F</td>
<td>62</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>4</td>
<td>1000</td>
<td>30.41667</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier G</td>
<td>66</td>
<td>0</td>
<td>4</td>
<td>12</td>
<td>10</td>
<td>1000</td>
<td>30.41667</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier H</td>
<td>24</td>
<td>23</td>
<td>31</td>
<td>104</td>
<td>22</td>
<td>1000</td>
<td>3.509615</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Supplier I</td>
<td>1</td>
<td>1</td>
<td>1000</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier J</td>
<td>1</td>
<td>1</td>
<td>1000</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier K</td>
<td>1</td>
<td>1</td>
<td>1000</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier L</td>
<td>1</td>
<td>1</td>
<td>1000</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.4: Inbound logistics decision support model: Cross-dock input parameters

For the Vendor Managed Inventory SCC’s more information has to be filled in since also data from the supplier is needed. Again the grey cells are obligatory to be filled in, but a choice can be made whether the distance between the supplier and the factory is determined by the grid coordinates or that the distance is directly filled in as can be seen in figure 8.5.
VMI Supplier 1

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f_u)</td>
<td>1</td>
<td>km/coordinate</td>
<td>Distance traveled over one grid coordinate (from ([0,0]) to ([0,1]))</td>
</tr>
<tr>
<td>beta</td>
<td>1</td>
<td>-</td>
<td>Ordering efficiency factor of the supplier</td>
</tr>
<tr>
<td>(p)</td>
<td>11520</td>
<td>units (pallets)</td>
<td>Annual production capacity</td>
</tr>
<tr>
<td>(p_c)</td>
<td>10</td>
<td>%</td>
<td>Supplier carrying cost per euro of inventory per year</td>
</tr>
<tr>
<td>(p_{release})</td>
<td>25</td>
<td>euro/release</td>
<td>Suppliers order release costs</td>
</tr>
<tr>
<td>(p_{store,S})</td>
<td>91.25</td>
<td>euro/pallet/year</td>
<td>Suppliers annual cost of physical storage /pallet</td>
</tr>
<tr>
<td>(s)</td>
<td>250</td>
<td>euro/setup</td>
<td>Production setup cost of the supplier</td>
</tr>
<tr>
<td>(v_{truck})</td>
<td>32</td>
<td>pallets/truck</td>
<td>Number of pallets that fit in a truck</td>
</tr>
</tbody>
</table>

Factory location:

Distance supplier - factory (km) | 95

Supplier name | \(x\) | \(y\) | \(f_c\) | \(v_c\) | \(U\) | \(v_{pallet}\) | \(t_p\) | \(t_{q_p}\) | \(t_o\) |
---|---|---|---|---|---|---|---|---|
Supplier A | 51 | 48 | 24 | 1 | 1000 | 7.604167 | 5 | 5

Figure 8.5: Inbound logistics decision support model: VMI input parameters

JIT Supplier 1

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f_u)</td>
<td>1</td>
<td>km/coordinate</td>
<td>Distance traveled over one grid coordinate (from ([0,0]) to ([0,1]))</td>
</tr>
<tr>
<td>(n_{ship/order})</td>
<td>10</td>
<td>shipment/order</td>
<td>Number of shipments per order placed</td>
</tr>
<tr>
<td>(a_{JIT/liff})</td>
<td>2</td>
<td>euro/km</td>
<td>JIT transport price per km</td>
</tr>
<tr>
<td>(t_{day})</td>
<td>10</td>
<td>hours</td>
<td>Production hours per working day</td>
</tr>
<tr>
<td>(v_{truck})</td>
<td>32</td>
<td>pallets/truck</td>
<td>Number of pallets that fit in a truck</td>
</tr>
</tbody>
</table>

Factory location:

Distance supplier - factory (km) | 95

Supplier name | \(x\) | \(y\) | \(f_c\) | \(v_c\) | \(U\) | \(v_{pallet}\) | \(t_p\) | \(t_{q_p}\) | \(t_o\) |
---|---|---|---|---|---|---|---|---|
Supplier A | 51 | 48 | 24 | 1 | 1000 | 7.604167 | 5 | 5

Figure 8.6: Inbound logistics decision support model: JIT input parameters

To be able to assess the effect of a SCC a table for the current situation has been included. In this table, that can be seen in figure 8.7 on the next page, every unique supplier that has been used in the SSC's has to be included with the corresponding information. However, the complete supplier base can be filled in here as well to calculate the current inbound logistic costs that a company is paying.
Figure 8.7: Inbound logistics decision support model: Input of all suppliers

In the flowchart of the Excel model, it was visible that the information filled in on the input worksheet was copied to the calculation models. However, illustrating the worksheets of these calculation models is less relevant for the user. So therefore it is decided that they are not be presented here. If the reader is interested in this information, a blank version of the model can be found on the CD-rom that can be found in appendix F.

What is relevant for the user, is the output worksheet with detailed information on the effects of the SCC’s and the ranking of SCC’s based on either the results on total cost reduction or on a lower amount of invested capital. Both worksheets can be seen in figures 8.8 (ranking) and 8.9 (detailed output) in which the results in the latter one are sorted on the maximum total cost reduction. It is realized by the researcher that it is impossible to read the detailed output worksheet. Therefore for each concept, a separate figure presents the table with the detailed output (see figures 8.10, 8.11, 8.12, 8.13 and 8.14).

Figure 8.8: Inbound logistics decision support model: Ranking SCC’s
Figure 8.9: Inbound logistics decision support model: Detailed output

Figure 8.10: Detailed output: Current situation
**Milk-run 1**

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Name (Optional)</th>
<th>New order quantity (pallets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>7</td>
<td>5.97</td>
</tr>
<tr>
<td>Supplier B</td>
<td>60</td>
<td>2.99</td>
</tr>
<tr>
<td>Supplier C</td>
<td>61</td>
<td>2.86</td>
</tr>
<tr>
<td>Supplier D</td>
<td>54</td>
<td>16.18</td>
</tr>
</tbody>
</table>

**Transport costs**
- Current situation: €263.057
- Milk-run situation: €278.193
- Relative difference: 5.78%
- Absolute difference: €15.135

**Inventory costs**
- Current situation: €51.571
- Milk-run situation: €66.586
- Relative difference: 5.35%
- Absolute difference: €15.015

**Order costs**
- Current situation: €10.740
- Milk-run situation: €15.495
- Relative difference: 44.91%
- Absolute difference: €4.755

**Total costs**
- Current situation: €337.961
- Milk-run situation: €428.366
- Relative difference: 8.68%
- Absolute difference: €24.405

**Figure 8.11: Detailed output: Milk-run**

**Cross-dock 1**

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Name (Optional)</th>
<th>New order quantity (pallets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>6</td>
<td>2.99</td>
</tr>
<tr>
<td>Supplier B</td>
<td>8</td>
<td>0.37</td>
</tr>
<tr>
<td>Supplier C</td>
<td>11</td>
<td>1.12</td>
</tr>
<tr>
<td>Supplier D</td>
<td>17</td>
<td>0.37</td>
</tr>
<tr>
<td>Supplier E</td>
<td>35</td>
<td>4.04</td>
</tr>
<tr>
<td>Supplier F</td>
<td>62</td>
<td>0.37</td>
</tr>
<tr>
<td>Supplier G</td>
<td>66</td>
<td>1.93</td>
</tr>
<tr>
<td>Supplier H</td>
<td>24</td>
<td>1.78</td>
</tr>
</tbody>
</table>

**Transport costs**
- Current situation: €263.057
- Cross-dock situation: €445.185
- Relative difference: 69.21%
- Absolute difference: €182.127

**Inventory costs**
- Current situation: €51.571
- Cross-dock situation: €47.889
- Relative difference: 8.90%
- Absolute difference: €3.718

**Order costs**
- Current situation: €10.740
- Cross-dock situation: €22.115
- Relative difference: 106.84%
- Absolute difference: €22.215

**Total costs**
- Current situation: €337.961
- Cross-dock situation: €538.253
- Relative difference: 59.26%
- Absolute difference: €200.292

**Figure 8.12: Detailed output: Cross-dock**
The main criteria used in this decision support model to determine the ranking of the SCC's are the total inbound logistic costs and the invested capital. For a full evaluation of the SCC's other criteria can and should be included as well. The most prominent criteria that could be added to the decision support model are the service level and flexibility of the solutions.

So a better approximation of the transport costs and an extended evaluation are the two main improvements identified by the researcher. With this last note on the inbound logistic decision support model, the model can be applied in a case study. But before this case study can be performed, the process of identifying supplier-concept-combinations is described in the next chapter.
Chapter 9

Supplier mapping and identification of supplier-concept-combinations

In the past chapters, all calculation models have been developed that can be used to quantify effects of the four included inbound logistic concepts and the decision support model was constructed. However, it has not yet been described how to get from a supplier base of a factory and the four logistic concepts to the required input data for the calculation models. How this is done will become clear in this chapter.

As was already mentioned at the end of chapter 4, the problem of connecting suppliers to the included concepts has two dimensions. These two dimensions are: (1) selecting the best performing supplier or group of suppliers per concept and (2) find the optimal supplier classification so that they are only connected to one concept. From an academic perspective this is a combinatorial problem that can be solved mathematically. However, for the time span of this research and the focus on designing a decision support tool, it is chosen by the research to take a soft pragmatic approach but a follow-on on this research can be the construction of a tool to solve this combinatorial problem. The chosen approach for the research is mapping the suppliers and connecting them to the concepts based on selection rules. This method is simple to develop compared to a mathematical solution and will give a satisfying result as well. The process of mapping and selecting suppliers will be explained in this chapter.

Before these processes are introduced, the major requirements of the four concepts will first be recalled in the next section and further evaluated to set the final requirements that are used for the mapping process.

9.1 Defining the requirements

In this section, the requirements presented in chapter 4 are combined with the results of the sensitivity analysis of each concept. This will lead to a new set of requirements. It should be noted that only the requirements related to the shipping quantity, demand pattern and shipping conditions are taken from chapter 4.
9.1.1 Milk-run

When the requirements presented in chapter 4 and the results of the milk-run sensitivity analysis (paragraph 7.2.4) are combined and evaluated, it results in the following list:

- Requirements from chapter 4:
  - Partial loads
  - Stable demand
  - Compatible transport conditions

- Results from the sensitivity analysis (paragraph 7.2.4):
  - Number of suppliers is maximal
  - Distance to the factory is maximal
  - Distance between suppliers in minimal

Though it is chosen by the researcher that the partial loads requirements will not be considered very strictly since full truckload shipments can also be split in partial loads with a higher frequency. Another point that has to be kept in mind is that the average distance between suppliers in the milk-run is not larger than the average distance from these suppliers to the factory because this will lead to more kilometers driven and also higher costs in the new situation.

The closer to each other the suppliers are, the better the result of a milk-run will be. Therefore it is decided by the researcher that the suppliers should initially be located in a circle with a diameter of 100 kilometer.

9.1.2 Cross-dock

For cross-docking the following four requirements were presented in chapter 4:

- Partial loads
- Stable demand
- High yearly volume
- Compatible transport and handling conditions

In the sensitivity analysis it became clear that cross-docking will not be suitable within a range of 500 kilometer from the factory. Even in range of 1000 kilometer this might not be the case, but to be on the safe side it is chosen that the minimal distance between the factory and the cross-dock facility is 500 kilometers. In this same sensitivity analysis, it was also shown that a high yearly volume is not necessary since it was already beneficial with four suppliers that ship 8 pallets 24 times a year (in total 192 pallets per year per supplier) so the requirement is considered to be less important.

9.1.3 Vendor Managed Inventory

For implementing Vendor Managed Inventory a company should search for a supplier that fits the following requirements:

- Constant flow
- Single-sourcing supplier
- Short supplier-factory distance
It can be expected that the shipping frequency will increase under Vendor Managed Inventory, so the distance from the supplier to the factory should not be too large. However, no limit will be considered here. What should be kept in mind is that the buyer is not the largest one of the supplier. Here should be thought about a share of around 75% and higher because this will lead to high production and shipment release cost for the supplier. In the end this can be translated in a VMI situation that will not be beneficial.

9.1.4 Just-in-Time delivery

In total three requirements were stated for the Just-in-Time delivery concept: (1) predictable demand, (2) single-sourcing supplier and (3) short supplier-factory distance. This latter requirement was also supported by the sensitivity analysis because for this concept, the transport price is by far the greatest cost component and the distance is the second most important parameter. So therefore it is decided by the researcher that the supplier should be located within a 250 kilometer radius from the factory.

9.1.5 General conclusion on requirement

In the previous paragraphs, the requirements per concept have been discussed. When the requirements are compared, it can be seen that for JIT and VMI the supplier should be a single-sourcing supplier. For the concepts that consolidate shipments (milk-run and cross-dock) the shipment size and the shipping condition are important. For the milk-run and the cross-dock solutions, also the shipping frequency will be a useful indicator in the identification of the suppliers per concept.

Also for VMI and JIT the shipment size and frequency is relevant, so therefore the following four indicators will be used for the mapping procedure that is described in the next section:

- Single-sourcing supplier
- Shipment size
- Shipping frequency
- Shipping condition

9.2 Mapping of suppliers

The fastest way of identifying possible combinations of suppliers and concepts by the human brain is by visualization of the situation. This can also be applied here for identification of possible supplier-concept-combinations (SCC's) and therefore it is chosen to map all suppliers based on their geographical location.

For mapping the suppliers it is important that the geographical location, shipment frequency (demand pattern) and shipment size can be easily interpreted. Therefore not all suppliers are mapped since this number can reach up to 150 individual suppliers for a single factory.

To reduce the number of suppliers for the mapping process it is possible to use the 80-20 rule and take the top 20 suppliers based on yearly volume. This will result in a map where only the largest suppliers are presented while a large part of the opportunities is on consolidating smaller shipments and thus requires these smaller suppliers. The real small suppliers however can be left out and this will be done according to following criterion:

- \( V_i \geq 48 \): The supplier delivers at least 48 pallets per year which is equal to 4 pallets per month.

\(^{20\%}\) of the suppliers deliver 80\% of the volume
The remaining suppliers have to be mapped in such a way that the identification of supplier-concept-combination is done easily and quick. In the previous section four indicators for mapping suppliers have been presented, but these indicators have to be divided in different classes and be represented by different markings to ensure a quick identification process. This all will be introduced in the next paragraphs per indicator.

9.2.1 Shipping frequency

One of the two important properties of a supplier for consolidation is the shipping frequency. When considering the shipping frequencies that occur at Danone Baby Nutrition (based on the factories in Fulda, Germany, and Opole, Poland) it becomes clear that a classification based on the average deliveries per month can made as follows:

- 1 or less deliveries per month;
- 2 to 3 deliveries per month;
- 4 deliveries or more per month.

So the majority in the first class will deliver once a month since the other ones are too small and thus excluded. A frequency of 3 times a month is rare and therefore added to the second class, so again the majority of the suppliers in this class will supply their products twice a month. When a supplier delivers every week, this will lead to an average of 4.33 deliveries per month and will therefore be located in the last class. To indicate these three classes different, colours are used which will be red for 1 or less deliveries per month, yellow for 2 to 3 deliveries per month, and green for 4 or more deliveries per month.

9.2.2 Drop-size

Besides the frequency of the deliveries also the drop-size (shipment size) is an important property of a supplier when looking at inbound logistic concepts that can be used. This property will be indicated on the map by the size of the location marker. Based on practical data of the factories in Germany and Poland, it was revealed that a lot of deliveries have a low drop quantity. So it is important to have small classes in this range. On the other side it is important to limit the number of classes/dot-sizes to be able to simply identify the drop-size on the map. In the end it is chosen to have four drop-size classes respecting the previous mentioned restrictions:

- 2-5 pallets;
- 6-10 pallets;
- 11-20 pallets;
- 20+ pallets.

9.2.3 Shipping condition

The supplied products are transported with three possible shipping conditions when looking at the temperature. These conditions are ambient, where there is no temperature control, chilled/conditioned in which the products are chilled or the temperature is maintained at a certain level and frozen. To indicate these three different conditions, which are of minor importance compared to the previous two properties, three shapes are used:

- Ambient: a circle;
- Chilled/conditioned: a rectangle;
- Frozen: a triangle (\(\triangledown\)).
9.2.4 Single-sourcing suppliers

The last property that has to be incorporated in the mapping is whether a supplier is a single-sourcing supplier or not. To indicate this on the supplier map an S will be presented inside the location marker.

9.2.5 Overview location markers

In this paragraph an overview of the location markers is presented in accordance with the classification stated in this section and includes the shipping frequency, drop-size in pallets, shipping condition and single-sourcing supplier indication. This leads to figure 9.1.

<table>
<thead>
<tr>
<th>Shipping frequency</th>
<th>Drop-size</th>
<th>Shipping condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 1 delivery per month</td>
<td>2 - 5 pallets</td>
<td>Ambient</td>
</tr>
<tr>
<td>2 - 3 deliveries per month</td>
<td>6 - 10 pallets</td>
<td>Chilled/conditioned</td>
</tr>
<tr>
<td>≥ 4 deliveries per month</td>
<td>11 - 20 pallets</td>
<td>Frozen</td>
</tr>
<tr>
<td>S Single-sourcing supplier</td>
<td>&gt;20 pallets</td>
<td></td>
</tr>
</tbody>
</table>

Figure 9.1: Indicators and classes used for mapping suppliers

9.2.6 Data requirements

Before the mapping process can start, data on the supplier base has to be collected. The first step in this data collection is to get a list of all suppliers of a factory. For each of these suppliers, the following information has to be collected:

- Average drop-size
- Average number of deliveries per year
- Single-sourcing supplier: Yes/No
- Shipping condition: Ambient/Chilled/Frozen
- Shipping address

Now that is clear how the suppliers are mapped to speed up the identification process, the process of identifying combinations of suppliers and concepts can be introduced.

9.3 Procedure of identifying concept-supplier combinations

With the mapping indicators described in the previous section, the suppliers of a factory can be mapped according to these indicators and corresponding classes. With a supplier map, so-called supplier-concept-combinations can be identified. These supplier-concept-combinations are unique situations in which one or more suppliers are related to one of the four logistic concepts and have already been introduced in chapter 5. Multiple supplier-concept-combinations can be identified and it is also possible that a supplier is at first instance related to two concepts in two different supplier-concept-combinations (SCC). In this section the process of identifying the SCC's will be described per concept. In the end attention is paid how to deal with suppliers that are included in multiple SCC's that have a positive result on the criteria. For each of the SCC's it should be noted that the data collected for the mapping process will also be the input data for the inbound logistic decision support model.
9.3.1 Milk-run

For the milk-run concept it is important that the suppliers are located close to each other (located in a circle with a radius of 50 km as was determined before) and have partial loads with compatible shipping conditions. To identify milk-run SCC's a group of 4 to 6 suppliers has to found that matches these requirements. When one or more of such groups are identified, the data can be put in the inbound logistic decision support model. Of this data the location of the suppliers is noted in grid coordinates, so a grid has to be drawn over the map to be able to deliver this input data.

Due to the constraint that limits the number of suppliers of the map, it is possible that there are small suppliers located in the circle of the identified milk-run SCC that are initially excluded for the mapping procedure. These suppliers will not be included in the calculation model, but can be included when the milk-run is realized in practice.

9.3.2 Cross-dock

The process for identifying cross-dock SCC's is similar to the one of the milk-run SCC’s, however in this case a circle with a radius of 500 kilometers around the factory has to be drawn and the SCC’s have to be found outside this circle. Despite the fact that the result of a cross-dock will improve when the suppliers are located closer to each other, no specific constraint exists for the distance between the suppliers. So for the cross-dock SCC’s a group has to be found with matching shipping conditions and partial loads.

Here also holds that small suppliers will not be included for the analysis but can be included in practice.

9.3.3 Vendor Managed Inventory

Only single-sourcing suppliers are suitable for the concept of Vendor Managed Inventory, so all other suppliers can be skipped directly. Suppliers that are located more than 500 kilometers from the factory are excluded. Because it is difficult to establish a strict guideline on which suppliers have to be selected, it is also advised that the supplier selected for Vendor Managed Inventory is not too small. For the remaining suppliers more research has to be performed on their delivery performance and whether the demand pattern is constant or not.

9.3.4 Just-in-Time delivery

The last concept is Just-in-Time delivery and for this concept a circle with a radius of 250 kilometers has to be drawn around the factory. Within this circle a single-sourcing supplier has to be found with a predictable demand. For this last requirement more research has to be performed in addition to the data that has already been collected. It is advised to select a medium-sized or large supplier to ensure that the demand is sufficient for this concept.

9.3.5 Dealing with overlapping SCC’s

In the described selection procedure to connect suppliers to one of the four concepts, it is likely that a supplier is combined with two or even more concepts. In practice however, a supplier can only implement one concept. To select which concept this will be, a set of rules is established based on the performance that is calculated with the model. With the following rules, the user is able to determine what the best solution is when a supplier is connected to two concepts that both yield a positive result. When a concept is not resulting in reduced cost or a lower amount of invested capital it should not be implemented. In the rules stated on the next page, supplier X is the supplier that is connected to two concepts.
• **JIT and VMI:** Compare the savings obtained in both cases and connect supplier X to the best performing concept.

• **Milk-run and cross-docking:** Compare the results of the following combinations and select the one with the best result:
  - Milk-run with supplier X + cross-dock **without** supplier X
  - Milk-run **without** supplier X + cross-dock with supplier X

• **JIT or VMI and milk-run or cross-docking:** As was the case for the milk-run and cross-docking decision, the user has to select the best performing option out of the following two:
  - JIT or VMI + Milk-run or cross-docking **without** supplier X
  - Milk-run or cross-docking **with** supplier X

So based on the results obtained by the concepts, a decision can be made to which concept the supplier has to be connected and has to implement. When the supplier is connected to three concepts in the identification process, first one concept has to be ruled out. This has to be done as follows for these scenarios:

• **JIT + VMI + Milk-run or JIT + VMI + Crossdock:** First compare JIT with VMI and eliminate one of them. This leaves a comparison of two concepts so that the previously presented rules can be used.

• **Milk-run + Cross-dock + VMI or JIT:** In this case the best one has to be selected out of a number of combinations:
  - Milk-run **without** supplier X + Cross-dock **without** supplier X + VMI or JIT
  - Milk-run **without** supplier X + Cross-dock with supplier X
  - Milk-run with supplier X + Cross-dock **without** supplier X

In the exceptional case that the supplier is connected to four concepts, first VMI has to be compared with JIT. This makes it possible to eliminate one of them so that the last scenario with three concepts remains and this can be solved as described above.

When multiple suppliers are in the same cluster for a milk-run or for cross-docking and are connected to two or more concepts, more combinations exist. But in general the same way of thinking can be applied in this case as for the rules presented before.

With these rules for when a supplier is connected to multiple concepts, the ins and outs of the inbound logistic decision support model have been presented. Now this theoretical approach is connected to the reality by applying it in a case study for Danone Baby Nutrition in the next chapter.
Chapter 10

A case study for the Opole factory of Danone Baby Nutrition

In the last chapters an inbound logistics decision support model has been developed. This model enables the quantification of possible savings realized by a milk-run, cross-dock, Vendor Managed Inventory or Just-in-Time delivery. With the output of this model, the user can make a decision which steps to take to improve the inbound logistics. Because this model is in first instance developed for Danone Baby Nutrition, a case study will be formed for their factory in Opole, Poland. This specific factory has over 150 individual suppliers located all over Europe. This chapter guides the reader through this case study by first presenting the application of the mapping and identification procedure. With these results, the data for the decision support model is gathered so that the effects can be calculated. In the end the results are discussed and a conclusion is drawn for this particular factory of Danone Baby Nutrition.

10.1 Mapping supplier and identification of SCC’s

The first step in obtaining the effects of a concept is mapping the suppliers of a factory and identifying supplier-concept-combinations (SCC’s). This will be done in this section by first presenting the supplier map. With this supplier map the SCC’s are identified and the data of these SCC’s is presented in the last paragraph.

10.1.1 Mapping the suppliers

So the Opole plant has over 150 suppliers, but not all of them will be mapped because they have to fulfil the boundary condition presented in section 9.2. Here it was stated that the total yearly volume of the supplier has to be at least 48 pallets which is equivalent to 4 pallets each month.

As a result of this minimal yearly volume, only 68 individual suppliers remain. However, these 68 suppliers are responsible for 98% of the volume shipped to Opole. For these suppliers their shipping addresses and thus not their office location is collected. By gathering this data, it becomes clear that there are multiple suppliers that have more than one shipping address. All these shipping addresses are included and later on it will be checked whether one supplier has multiple locations in one SCC’s.

Applying the indicators and corresponding classes presented in section 9.2 leads to the supplier map depicted on the next page.
Figure 10.1: The suppliers of the factory in Opole mapped
10.1.2 Identification of supplier-concept-combinations

With the map presented on the previous page, a number of supplier-concept combinations (SCC’s) can be identified. For purpose of this identification process, two circles are drawn in this map as well and indicate the 250 and 500 kilometer radius around the factory (indicated by the a factory symbol). In this paragraph more attention is paid the identification of the SCC’s.

A Just-in-Time supplier should be of medium to large size and located in a radius of 250 kilometer around the factory. In this case study, this means that only two suppliers are suitable. The first one is the green circle east of the factory while the second one is located northwest of the factory and is also marked by a green circle. Since both of these suppliers fulfil the JIT requirements, they are included in the model. However, these are two different shipping locations of the same supplier, so therefore it is chosen to only include the location closest to the factory. Also one supplier that is just outside this range is selected because this supplier already ships almost twice a week to the factory. This supplier is located in the cluster near Poznion, northwest of the factory in Opole.

Because more suppliers fulfil the single-sourcing requirement for Vendor Managed Inventory, it is chosen to only select suppliers that deliver frequently to the factory and thus at least 4 times per month. Because only three suppliers can be included in the model, a selection has to be made on which suppliers are incorporated. This is mostly based on the demand pattern and this leads to one supplier east of the factory with a stable demand pattern, one supplier just below Magdeburg (Germany) and one supplier in the north of the Netherlands. These three suppliers enable the researcher to see whether the distance is really important for the VMI effects.

Figure 10.2: Map of supplier-concept-combinations
In the blink of an eye, three milk-run clusters can be identified: one around Hamburg, one just northeast of München and one around Poznan in Poland (northwest of the factory on the 250 kilometer radius). When taking a closer look at the first one it seems less suitable since not all suppliers have the same shipping condition and will thus not be included in the analysis. In order to fulfill the requirements that the suppliers should be located in a circle of 100 km, only four of the six suppliers northeast of München can be included. These are the three around the circle of the 500 km radius and the green circle just below them. The cluster around Poznan in Poland consists of four suppliers and obliges all requirements. So for the case study, two milk-run clusters are included.

Only for the cross-dock concept still one or multiple SCC’s have to be identified. Looking for clusters with the same transport condition that are located more than 500 kilometer from the factory only one feasible cluster remains in the Netherlands with all suppliers that are shipping their products on the ambient temperature. One supplier located in Belgium between Bruges and Brussels can be incorporated in this cluster as well thereby bringing the count to 8 suppliers since one supplier has two shipping locations in this cluster (Breda and Etten-Leur).

So there are two Just-in-Time SCC’s, three for VMI, two for a milk-run and one for cross-docking and results in a total of 8 supplier-concept-combinations. The exact locations of these SCC’s they are indicated on the map in figure 10.2. As can be seen from this map, there are a number of suppliers that are involved with multiple SCC’s but this will be discussed if this leads to a dilemma after the results are presented.

### 10.1.3 Data of the supplier-concept-combinations

The general input parameters are determined in the next section, but first the data of the identified SCC’s in the last paragraph are presented. This data is extracted from the list of all suppliers that are mapped. The complete list can be found in appendix G. For each of the concepts there is one table for the related SCC data presented below.

#### Table 10.1: Data of the Vendor Managed Inventory supplier-concept-combinations

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Yearly volume deliveries [pallets]</th>
<th>Yearly deliveries [-]</th>
<th>Drop size [pallets]</th>
<th>Distance to factory [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMI 1</td>
<td>51</td>
<td>1152</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
<td>VMI 2</td>
<td>59</td>
<td>1440</td>
<td>48</td>
<td>30</td>
</tr>
<tr>
<td>VMI 3</td>
<td>24</td>
<td>2288</td>
<td>104</td>
<td>22</td>
</tr>
</tbody>
</table>

#### Table 10.2: Data of the Just-in-Time supplier-concept-combinations

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Yearly volume deliveries [pallets]</th>
<th>Yearly deliveries [-]</th>
<th>Drop size [pallets]</th>
<th>Distance to factory [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>JIT 1</td>
<td>51</td>
<td>1152</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
<td>JIT 2</td>
<td>10</td>
<td>3168</td>
<td>96</td>
<td>33</td>
</tr>
</tbody>
</table>
Table 10.3: Data of the cross-dock supplier-concept-combination

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Yearly volume deliveries [pallets]</th>
<th>Yearly deliveries [-]</th>
<th>Drop -size [pallets]</th>
<th>Grid coordinate X</th>
<th>Grid coordinate Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>384</td>
<td>48</td>
<td>8</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>48</td>
<td>48</td>
<td>1</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>144</td>
<td>12</td>
<td>12</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>17</td>
<td>48</td>
<td>12</td>
<td>4</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>24</td>
<td>2288</td>
<td>104</td>
<td>22</td>
<td>23</td>
<td>31</td>
</tr>
<tr>
<td>35</td>
<td>520</td>
<td>52</td>
<td>10</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>62</td>
<td>48</td>
<td>12</td>
<td>4</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>66</td>
<td>120</td>
<td>12</td>
<td>10</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Factory</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Factory 106 0

Table 10.4: Data of the milk-run supplier-concept-combinations

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Yearly volume deliveries [pallets]</th>
<th>Yearly deliveries [-]</th>
<th>Drop -size [pallets]</th>
<th>Grid coordinate X</th>
<th>Grid coordinate Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk-run SCC 1</td>
<td>7 576 48 12 9 16</td>
<td>54 1560-3120 52-104 30 7 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>288</td>
<td>12</td>
<td>24</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>61</td>
<td>276</td>
<td>12</td>
<td>23</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Factory</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk-run SCC 2</td>
<td>10 3168 96 33 5 81</td>
<td>13 168 24 7 9 80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>576</td>
<td>48</td>
<td>12</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>51</td>
<td>1152</td>
<td>48</td>
<td>24</td>
<td>7</td>
<td>82</td>
</tr>
<tr>
<td>Factory</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Taking a closer look at this data learns that there are suppliers 24 and 51 are connected to multiple SCC's. These are suppliers 24 and 51. As mentioned before, this will be discussed when the effects of the SCC's are quantified. However, this is not all the data that has to be put into the decision support model, so the remaining general data will be presented in the next section.

### 10.2 Determining and estimating input parameters

In the previous section the supplier-concept-combinations have been identified and contains the data of these SCC's. However, before any results can be presented a lot more data has to be gathered. The data that still has to be collected can be split in two types: the general parameters that are independent of a concept and the concept specific data. First these general parameters are presented followed by the concept specific data.
10.2.1 General parameters

This paragraph contains values for the general parameters that are needed as input for the inbound logistic decision support model. Because these values have different sources they are listed per source. It should be noted that the values presented here are meant for the Opole factory of Danone Baby Nutrition. So when the model is used for another factory or even for another company, these values have to be checked and adapted when necessary.

Table 10.5: General input parameters from Lolonis (2009)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_{\text{order}} )</td>
<td>15</td>
<td>euro/order</td>
<td>Ordering cost per order</td>
</tr>
<tr>
<td>( p_{\text{carrying}} )</td>
<td>8</td>
<td>%</td>
<td>Carrying cost per euro of inventory per year</td>
</tr>
<tr>
<td>( v_{\text{pallet}} )</td>
<td>1000</td>
<td>euro/pallet</td>
<td>Average pallet value</td>
</tr>
</tbody>
</table>

Table 10.6: General input parameters from van der Vlist (2007)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e )</td>
<td>30</td>
<td>km</td>
<td>Empty kilometers after unloading</td>
</tr>
<tr>
<td>( p_{\text{docking}} )</td>
<td>30</td>
<td>euro/truck</td>
<td>Cost for docking a truck</td>
</tr>
<tr>
<td>( p_c )</td>
<td>3</td>
<td>euro/pallet</td>
<td>Cost of cross-docking one pallet</td>
</tr>
<tr>
<td>( p_{\text{store}} )</td>
<td>91.25</td>
<td>euro/pallet/year</td>
<td>Annual cost of physical storage per pallet</td>
</tr>
</tbody>
</table>

Table 10.7: General input parameters collected by the researcher

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_d )</td>
<td>1.2</td>
<td>-</td>
<td>Detour factor to convert a direct distance between Cartesian coordinates to driving distance</td>
</tr>
<tr>
<td>( p_{\text{km}} )</td>
<td>0.98</td>
<td>euro/km</td>
<td>Transportation price per km</td>
</tr>
<tr>
<td>( S_h )</td>
<td>15</td>
<td>euro/hour</td>
<td>Hourly salary of an inbound warehouse employee</td>
</tr>
<tr>
<td>( S_o )</td>
<td>17</td>
<td>euro/hour</td>
<td>Hourly salary of a buyer/ordering employee</td>
</tr>
<tr>
<td>( s_{\text{truck}} )</td>
<td>60</td>
<td>km/hour</td>
<td>Average driving speed of a truck</td>
</tr>
<tr>
<td>( t_{\text{check}} )</td>
<td>10</td>
<td>minute/hour</td>
<td>Time required to check a truck and transport documents</td>
</tr>
<tr>
<td>( t_{\text{drive}} )</td>
<td>9</td>
<td>hour/day</td>
<td>Maximal driving time per day for a truck driver</td>
</tr>
<tr>
<td>( t_{\text{unload}} )</td>
<td>3</td>
<td>minute/pallet</td>
<td>Time required to unload, check label and store incoming pallets</td>
</tr>
<tr>
<td>( v_{\text{FTL}} )</td>
<td>28</td>
<td>pallet</td>
<td>Number of pallets in a full truckload for the transport cost calculation</td>
</tr>
</tbody>
</table>

The data mentioned in the first two tables was directly taken from the corresponding resources, whereas the values presented in table 10.7 are collected and established by the researcher. Therefore more information will be given on their origin. First of all the detour factor \( f_d \), this value is determined by comparing the direct distance between two locations and the actual driving distance. For the transport price, tender results of Danone Baby Nutrition have been used and the average price per kilometer in this tender is used here. For the hourly rates of an inbound warehouse employee and a buyer/ordering employee respectively 80% and 90% of the gross modal income of the Netherlands is taken with 220 working year per year of 8 hours (Rijksoverheid, 2011). The average driving speed of a truck is an estimate of the researcher. The time for checking a truck and
unloading a truck is based on observations of the researcher during a factory visit. The number of pallets in a truck that is considered a full truckload for the transport cost calculation is based on the experience of a Danone Baby Nutrition employee. The last parameter on the maximum driving hours is taken from the Dutch law on driving times (Inspectie Verkeer en Waterstaat, 2011).

Besides these general parameters, there are also some concept specific ones that are presented in the next paragraph.

10.2.2 Concept specific parameters

In addition to all parameters presented until now, there are only a few more left before the effects of the SCC’s can be calculated. Before all these parameters are introduced, it is worth mentioning that for all suppliers included in this case study an average pallet value of 1000 euro is taken based on Lolonis (2009). This was also presented in table 10.5. Other data that is generalized for this case study are the production time, which is calculated on the time between replenishment actions, and the drop-size. Also the overlap and quality control duration are set on 5 days for all suppliers. Now the other parameters are presented per concept.

**Milk-run parameters**

Because the milk-run calculation model works with grid coordinates of both the suppliers and the factory, a conversion is needed from the distance in grid coordinates to an actual distance. The grid-size is the key for this conversion and each SCC has its own factor so therefore they are presented separately:

- Milk-run SCC 1: 5 km/unit
- Milk-run SCC 2: 2.4 km/unit

Two other values that are needed, are the time needed to arrange a milk-run and the number of pallets that fit in a full truck. For the first one a value of 30 minutes is estimated by the researcher. Normally a truck can fit up to 33 euro pallets, however when planning a milk-run on this maximum value it is impossible to accommodate a small variation or include small suppliers that have not been mapped. So therefore a load factor of 85% of the maximum is taken and this leads to 28 pallets per truck ($v_{sync}$). These last values are taken for both milk-run related SCC’s.

**Cross-docking parameters**

Also for the cross-docking SCC a conversion factor is needed and is in this case equal to 9.6 kilometer per grid unit. Again a maximum load of 28 pallets is taken for $v_{sync}$ as was also done for the milk-run SCC’s. Then there are only two parameters left, the transport price to the cross-dock center and the time needed to arrange an inbound shipment that uses a cross-dock construction. For the latter one 15 minutes is estimated by the researcher since this requires less work compared to a milk-run. The transport price to the cross-dock center is higher because this involves short distance transport. Based on the tender performed by Danone Baby Nutrition this price is set on 2 euro per kilometer.

**Vendor Managed Inventory parameters**

In the calculation model of Vendor Managed Inventory, not only parameters of the buyer, which is in this case Danone Baby Nutrition, are required. Also data on the supplier is needed to perform the calculations. Since this information is not directly available, values from literature are taken and assumptions are made. For all situations it is assumed that Danone Baby Nutrition is responsible for 10% of the supplier’s sales and the supplier is performing the ordering process as efficient as Danone Baby Nutrition ($\beta = 1$). Where the milk-run and the cross-dock concepts
need space for variation, this is less important for the Vendor Managed Inventory concept since
this involves only one supplier. Thus it is decided by the researcher that the value here will be set
on 32 euro pallets \( [q_{ini}] = 32 \). And since only one supplier is involved, the distance from the
supplier to the factory is measured directly without the using grid coordinates.

For the storage costs, the same value as for Danone Baby Nutrition was taken from van der
Vlist (2007), leading to storage cost of 91.25 euro per pallet per year. The carrying cost per pallet
is assumed to be 10 percent of the pallet value. The setup cost and the release cost per shipment
are respectively set on 250 euro per setup and 25 euro per shipment release.

**Just-in-Time delivery parameters**

The final parameters that are presented are for the Just-in-Time deliveries. Again for this concept
the direct driving distance from the supplier to the factory is taken. Because this driving distance
is in the same range as from a supplier to the cross-dock center, also a transport price of 2 euro
per kilometer is taken. The maximum number of pallets in a truck is set on 32 pallets. Because
the Just-in-Time concept means that a lot of orders have to be placed in a short time span, it is
assumed by the researcher that the production plan is accurate enough to order for 10 deliveries
at the same time.

Now that all parameters have been presented, the results of the case study can be presented.

### 10.3 Discussing the effects of the supplier-concept-combinations

By using all presented parameter values, the effect for all supplier-concept combinations can be
calculated by using the inbound logistic decision support model. The output of this model is both
on total costs, and its four cost components, and on the invested capital. First of all, this resulted
in the following current costs (rounded on 100 euro):

- Transport cost: €263100
- Inventory cost: €51600
- Handling cost: €12600
- Ordering cost: €10700

So the total current costs are €338000 while the invested amount of capital is €301100. These
numbers are the basis for the comparison because this current situation includes all unique sup­
pliers used in the eight SCC’s and is thus the base case for all SCC’s.

In tables 10.8 and 10.9 the effects of the SCC’s on the cost components and the invested cap­
ital are presented. These results are again rounded on 100 euro.

**Table 10.8: Absolute SCC results on costs in euro**

<table>
<thead>
<tr>
<th>SCC</th>
<th>Transport cost</th>
<th>Inventory cost</th>
<th>Handling cost</th>
<th>Ordering cost</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMI 3</td>
<td>-5700</td>
<td>800</td>
<td>-100</td>
<td>-1600</td>
<td>6600</td>
</tr>
<tr>
<td>VMI 1</td>
<td>500</td>
<td>-200</td>
<td>0</td>
<td>-700</td>
<td>-400</td>
</tr>
<tr>
<td>VMI 2</td>
<td>4400</td>
<td>-500</td>
<td>0</td>
<td>-700</td>
<td>3300</td>
</tr>
<tr>
<td>Milk-run 1</td>
<td>15100</td>
<td>-5200</td>
<td>-100</td>
<td>4700</td>
<td>14600</td>
</tr>
<tr>
<td>Milk-run 2</td>
<td>17800</td>
<td>-4100</td>
<td>-100</td>
<td>9100</td>
<td>22700</td>
</tr>
<tr>
<td>JIT 1</td>
<td>57100</td>
<td>-1800</td>
<td>800</td>
<td>-200</td>
<td>55900</td>
</tr>
<tr>
<td>JIT 2</td>
<td>63400</td>
<td>-2100</td>
<td>700</td>
<td>-900</td>
<td>61100</td>
</tr>
<tr>
<td>Cross-dock 1</td>
<td>182100</td>
<td>-3700</td>
<td>10400</td>
<td>11500</td>
<td>200300</td>
</tr>
</tbody>
</table>

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Table 10.9: Absolute SCC results on invested capital in euro

<table>
<thead>
<tr>
<th>SCC</th>
<th>Invested capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMI 3</td>
<td>4500</td>
</tr>
<tr>
<td>VMI 1</td>
<td>-1000</td>
</tr>
<tr>
<td>VMI 2</td>
<td>-2700</td>
</tr>
<tr>
<td>Milk-run 1</td>
<td>-30400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SCC</th>
<th>Invested capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk-run 2</td>
<td>-24000</td>
</tr>
<tr>
<td>JIT 1</td>
<td>-10400</td>
</tr>
<tr>
<td>JIT 2</td>
<td>-12200</td>
</tr>
<tr>
<td>Cross-dock 1</td>
<td>-2900</td>
</tr>
</tbody>
</table>

These first results are not really promising since only one supplier-concept-combination is realizing cost savings. This is only a small cost saving that will diminish when there are any unexpected costs. But after having a closer look at the input parameters for the cross-dock and milk-run SCC’s it is noticed that in all three SCC’s one large supplier is included compared to the other suppliers. These suppliers, which are: (1) nr. 54 in Milk-run 1, (2) nr. 10 in Milk-run 2 and (3) nr. 24 in Cross-dock 1, are removed from the clusters and also removed from the current situation if they are not used in another SCC. When this is done, better results are obtained as can be seen from tables 10.10 and 10.11. However, since the current situation is changed as well, different values are presented for the base case as well:

- Total cost: €295700
  - Transport cost: €229100
  - Inventory cost: €45300
  - Handling cost: €11300
  - Ordering cost: €10000
- Invested capital: €264800

Table 10.10: Improved SCC results on costs in euro

<table>
<thead>
<tr>
<th>SCC</th>
<th>Transport cost</th>
<th>Inventory cost</th>
<th>Handling cost</th>
<th>Ordering cost</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMI 3</td>
<td>-5700</td>
<td>800</td>
<td>-100</td>
<td>-1600</td>
<td>-6600</td>
</tr>
<tr>
<td>Milk-run 1</td>
<td>-1000</td>
<td>-2700</td>
<td>-100</td>
<td>1100</td>
<td>-2600</td>
</tr>
<tr>
<td>Milk-run 2</td>
<td>-2700</td>
<td>-1300</td>
<td>-100</td>
<td>1800</td>
<td>-2300</td>
</tr>
<tr>
<td>VMI 1</td>
<td>500</td>
<td>-200</td>
<td>0</td>
<td>-700</td>
<td>-400</td>
</tr>
<tr>
<td>VMI 2</td>
<td>4400</td>
<td>-500</td>
<td>0</td>
<td>-700</td>
<td>3300</td>
</tr>
<tr>
<td>Cross-dock 1</td>
<td>42400</td>
<td>-1800</td>
<td>3600</td>
<td>2200</td>
<td>46400</td>
</tr>
<tr>
<td>JIT 1</td>
<td>57100</td>
<td>-1800</td>
<td>800</td>
<td>-200</td>
<td>55900</td>
</tr>
<tr>
<td>JIT 2</td>
<td>63400</td>
<td>-2100</td>
<td>700</td>
<td>-900</td>
<td>61100</td>
</tr>
</tbody>
</table>

Table 10.11: Improved SCC results on invested capital in euro

<table>
<thead>
<tr>
<th>SCC</th>
<th>Invested capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMI 3</td>
<td>4500</td>
</tr>
<tr>
<td>Milk-run 1</td>
<td>-15400</td>
</tr>
<tr>
<td>Milk-run 2</td>
<td>-7500</td>
</tr>
<tr>
<td>VMI 1</td>
<td>-1000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SCC</th>
<th>Invested capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMI 2</td>
<td>-2700</td>
</tr>
<tr>
<td>Cross-dock 1</td>
<td>-3200</td>
</tr>
<tr>
<td>JIT 1</td>
<td>-10400</td>
</tr>
<tr>
<td>JIT 2</td>
<td>-12200</td>
</tr>
</tbody>
</table>

With removing the large suppliers in the milk-run and cross-dock clusters, the results did improve. But still the largest gain is made on the invested capital and not on the inbound logistic costs.
These results do not match the expectations based on the advantages presented in literature. These advantages are mentioned in chapter 4 and state for both the milk-run and cross-docking concepts that a reduction in transport cost is realized when using these concepts. For the milk-run concepts this is true, but for the cross-dock not, so therefore the results have to be analyzed and discussed in more detail. This will be done per concept in the following four paragraphs.

10.3.1 Discussing the milk-run results

When taking a look at the milk-run performance, it can be seen that the handling costs are slightly reduced. This result matches the expectation since there are fewer trucks that have to unload the same amount of pallets on a yearly basis. Before the transport and inventory costs are explained, first the details of both milk-run related SCC’s are presented:

- Delivery frequency (deliveries per year)
  - Milk-run 1: 40.7
  - Milk-run 2: 67.7
- Shipping volumes milk-run 1 (pallets)
  - Supplier 7: 14.15
  - Supplier 60: 7.07
  - Supplier 61: 6.78
- Shipping volumes milk-run 2 (pallets)
  - Supplier 13: 2.48
  - Supplier 44: 8.51
  - Supplier 51: 17.1

Based on these values, the difference in transport, inventory and ordering cost can be explained. First of all the ordering costs are increased because the number of orders that have to be placed has increased due to the new replenishment frequency. As a result of this new frequency, the drop sizes of the suppliers have decreased. This decrease in drop-size leads to lower inventory levels and thus also to lower costs. But when the pallet value of one or more suppliers changes, the inventory costs are affected as well. So the user has to be aware of the fact that this pallet value has to be determined for a reliable result.

The limited decrease in transport cost for both milk-run situations can be explained by looking in more detail to the equations used to calculate this transport cost in both the current and the milk-run situation (see paragraph 7.2.3). In a fictive situation where all suppliers have the same frequency and this frequency remains the same in the future (milk-run) situation, the number of shipments from one supplier to the factory remains constant. In this situation, the cost related to docking a truck and driving extra kilometers because of partial loads are decreased. On the other side extra full truckload kilometers are made since all suppliers have to be served before the truck can drive to the factory. Both parts are counteracting and the difference determines the result. However, when the replenishment frequency in a milk-run is higher than in the current situation, what is the case for milk-run 1 and 2, the advantage of a milk-run compared with the current situation will eventually disappear. So in the end it can be concluded that the milk-run shipping frequency compared with the current frequency of the suppliers and the distance between the suppliers are determining the results of a milk-run.\(^1\)

---

\(^1\)When the synchronization volume is increased from 28 to 32 pallets, this already strongly affects the result. If this is done, the total costs are reduced by €6000 while this is €2300 when the synchronization volume is 28 pallets.
10.3.2 Discussing the cross-docking results

Instead of reducing the total inbound logistic costs with cross-docking, the costs are dramatically increased. This is mainly due to an increase in transport costs. These higher transport costs are a result of the detour the shipments make via the cross-dock center and the high price per kilometer that has to be paid on the short distance to this cross-dock facility. Also the docking costs are higher, due to the fact that an extra stop is included at the cross-dock facility, and the handling costs are increased because an extra activity is added.

By shipping smaller quantities per supplier more frequently, the inventory levels reduce. As a result of this reduction, the inventory cost and the amount of invested capital reduce. But the reduction of the inventory cost is not of the same size as the increase in transport cost, so therefore the total costs rise. Important to notice is that also here the inventory costs are dependent on the pallet value and the accuracy of this value.

For now it can be said that cross-docking is not beneficial due to the high transport cost to the cross-dock facility and the minimal difference on the transport price per pallet between a partial load and a full truckload. This minimal difference is unable to compensate the high transport price and thus cross-docking is not beneficial. So therefore the researcher advises to perform a tender to verify the validity of the transport cost calculation on short distances with partial loads.

10.3.3 Discussing the Vendor Managed Inventory results

The results obtained by the three VMI SCC’s are not all pointing in the same direction. This can be explained by the new replenishment quantity that is used for the suppliers under VMI. Because this quantity is affecting both the transport and inventory costs. The current and new quantities can be found below, together with the classification of the VMI SCC.

- VMI 1: Supplier 51
  - Potential efficient for the buyer
  - Current drop size: 24 pallets - VMI drop size: 21.9 pallets

- VMI 2: Supplier 59
  - Inefficient
  - Current drop size: 30 pallets - VMI drop size: 24.5 pallets

- VMI 3: Supplier 24
  - Potential efficient for the buyer
  - Current drop size: 22 pallets - VMI drop size: 30.9 pallets

In a VMI scenario, the supplier chooses the replenishment quantity that minimizes its total cost. So this new quantity can be either higher or lower compared to the current drop size. However, the choice for the replenishment quantity directly influences the transport and inventory cost of the buyer, in this case Danone Baby Nutrition. A higher quantity leads to a lower replenishment frequency and thus to lower transport cost and higher inventory cost. The opposite occurs when the replenishment quantity is reduced. So the fact that the supplier sets the new replenishment quantity in its own favour, minimization of the total cost, explains the new replenishment frequency quantities for VMI 1, 2 and 3.
From the results it can be seen that VMI 3 is leading to the best result for Danone Baby Nutrition. This scenario leads to a cost reduction for Danone Baby Nutrition and is therefore classified as potential efficient for the buyer. However, a VMI scenario is only viable when there are system-wide cost savings because if this is not the case there is no reason to implement VMI from a cost perspective since either the buyer or the supplier is worse off compared to the current situation. These system-wide cost savings are only obtained by VMI 3 and not by VMI 1 that is also potentially efficient for the buyer. So in the end only VMI 3 will be viable for implementation, but the system-wide cost savings are only €4500 and this assessed by the researcher to be too low to be able to compensate for any unexpected costs that might occur.

10.3.4 Discussing the Just-in-Time results

The results of both Just-in-Time delivery SCC's are in line with the expectations. In a JIT situation the number of deliveries per year is higher compared to the current situation. However, the transport cost per pallet in this JIT situation is higher, thereby leading to increased transport cost.

The increase in transport cost should be compensated by reduced inventory levels and thus lower inventory costs. In this case, the pallet value of €1000 is too low to make up for the higher transport cost. Therefore it can be said that JIT might be profitable for high value products. So in case of a JIT supplier, the pallet value is of great importance for the performance of the concept. Despite the low pallet value, still a great reduction in invested capital is realized. But again, this is also dependent on the pallet value.

In case of the JIT concept, the main bottleneck to minimize the inventory levels are the quality check duration and the overlap. By having this quality check and thus also the overlap to ensure a continuous feed into the production, the minimal inventory level is constrained. So when a company uses JIT it should strive to minimize the quality check duration. However, it should be noted that the absolute difference between the current situation and the JIT is constant as long as the quality check is in both situations included or excluded.

10.4 Opole case study: conclusions and recommendations

The results that are obtained by the supplier-concept-combinations on the total cost are not large enough from the perspective of the researcher to stimulate the implementation of one of them. But based on the results and the discussions of each concepts performance, a number of conclusions can be drawn and recommendations can be made.

Despite the disappointing results of the concepts, this case study proofs that the model is working and gives insight in the performance of the included concepts. It also shows that the input of valid parameter values is very important for a reliable output. Therefore no final conclusions are drawn yet for the Opole factory, but it is advised by the researcher to first gather more accurate data and especially for the pallet value.

For the milk-run, cross-dock and JIT concepts it became clear that the assumption made on the pallet value have far going implications for the results that are presented for the inventory costs and invested capital. So before a final conclusion is drawn on the performance of these concepts, more accurate data has to be collected on the average pallet value\(^2\) of the related suppliers as was already mentioned. For JIT an additional conclusion can be presented that is related to the pallet value. Since the higher transport costs have to be compensated by lower inventory cost, only high value products are suitable for this concept if a total cost reduction is required.

\(^2\)The weighted average should be calculated here
Instead of realizing a transport cost reduction, the cross-docking scenario increased the transport cost and the gain for the milk-run SCC’s was only limited. For this case it is advised that the transport cost calculation is verified with a tender. Based on this tender, the values for parameters such as docking cost and the number of empty kilometers can be fine-tuned. With the tender results it can also be assessed whether the presented results are matching reality or not.

A special note has to be made on the results of the Vendor Managed Inventory related SCC’s. In order to obtain the results presented, assumptions have been made on the importance of Danone Baby Nutrition at the supplier and supplier specific parameters on the inventory holding cost, the ordering efficiency and the current production quantity. So the presented results give an impression of the possible results that can be obtained based on the assumptions made, but also here more accurate data has to be collected before a statement can be made.

With these conclusions and recommendations on this case study for the factory in Opole, the end of the research report is almost reached. The research will be finalized with a final conclusions and recommendations in the next chapter.
Chapter 11

Conclusions, recommendations and an academic reflection

The previous chapter contained a practical example of the inbound logistic decision support model applied for the Opole factory of Danone Baby Nutrition. With this case study, one of the sub-questions formulated in chapter 2 was answered. The other sub-questions have also been treated in this report and will be discussed in this conclusion. The only sub-question or partial design problem that is not included is the development of the calculation models because this will result in a list of equations that can also be found in related chapter(s) as well.

11.1 Danone Baby Nutrition and inbound logistics

When considering the supply chain of Danone Baby Nutrition, which is one of the four divisions within the company Danone, it all starts at the suppliers that can be divided into three categories: (1) raw material suppliers, (2) packaging suppliers and (3) factories of Danone Baby Nutrition that produce semi-finished goods and ship them to their other factories.

When the products are manufactured, they are shipped either directly to the national distribution centers or via an intermediate warehouse (primary warehouse). Products made at third-party manufacturers also arrive at these national distribution centers. From these distribution centers, five distribution channels to the consumer exist: (1) modern trade in-store sales, (2) modern trade internet sales, (3) traditional trade in-store sales, (4) baby stores and (5) hospitals and pharmacies.

Within the supply chain of Danone Baby Nutrition there are five trends that will lead to a different setup of this supply chain. One of them, Repetitive Flexible Supply, is influencing the inbound logistics by having a standard production schedule for a fixed period. This makes the demand of raw materials and packaging more predictable in advance.

When studying the inbound process of the supply chain in more detail, it can be concluded that this is a rather standard process with a normal ordering procedure, a quality check of the inbound materials and temporary (quarantine) storage before the production stage.

11.2 Inbound logistic concepts

With the information gathered on the inbound logistic process at Danone Baby Nutrition, a literature study and brainstorming sessions were performed by the researcher. This led to a total of four identified and included concepts: (1) a milk-run, (2) cross-docking, (3) Vendor Managed Inventory and (4) Just-in-Time delivery.
A milk-run can be considered as an inverse distribution run. In this case the loads are picked-up at the suppliers with one truck that drives to the factory when all suppliers are served. By means of this consolidation, the transport costs and dock occupation are reduced and the possibility exists to reduce the inventory levels by means of a higher shipping frequency. However, disturbances are hard to include and will affect part of the milk-run suppliers. For a milk-run it is required that the shipments are partial loads with the same transport temperature requirement.

The concept of cross-docking means that all suppliers ship their products to one warehouse, the cross-dock facility, where all these loads are transhipped in another truck. This truck then drives from the cross-dock facility to the factory. Again the same advantages of consolidation are valid here as was the case for the milk-run. However, disadvantages exist as well in the form of the need to synchronize orders and a longer lead time. The requirements match with the ones of the milk-run expanded with a high and stable demand for the products.

Only one supplier is involved with Vendor Managed Inventory, in which the stock is no longer managed by the buyer but by the supplier. This is done because the supplier has better insight in the demand and cost components. In the end this should lead to a higher service level, lower inventory levels and reduced transportation costs. But the supplier has to be the only supplier for that material (single-sourcing requirement), supplies products with a stable demand and with a standard design.

With the last concept of Just-in-Time delivery the products are delivered at the factory at the moment they are needed. In an ideal situation this removes the need for any inventory. In practice this will result in strongly reduced inventory levels and shorter lead-times, but increases the risk of production shut-down due to material shortage. To be suitable for this concept, the supplier has to be located close to the factory, be a single-sourcing supplier, his product has to have a predictable demand and the product has have a high value as became clear in the case study.

11.3 Combining the supplier base and the four concepts

To determine which concept performs best, each concept has to be connected to one or more suppliers (so-called supplier-concept-combinations) and evaluated against a set of criteria. The criteria that are used in this research are the total inbound logistic costs and the amount of capital invested in inventory, either stored at the factory or in transit.

The criterion of total inbound logistic costs is the sum of transport, inventory, handling and ordering costs. So general models have been developed for each of these four cost components and the invested capital. With these five general components, specific calculation models have been made to enable the quantification of the performance of the four included concepts.

Based on the performance of the supplier-concept-combinations, of which up to three different ones per concept can be included in the inbound logistic decision support model, they are ranked either on size of the total inbound logistic cost reduction or on the decrease of invested capital.

So summarized, the concepts are connected to one or more suppliers in unique supplier-concept-combinations. These combinations are the input for the concept performance models that calculate the effect on total cost and invested capital. When the results are known they can be ranked with regard to one of these two criteria.
11.4 Area of application, limitations and possible improvements of the decision support model

When considering the area in which the model can be applied, the conclusion can be drawn that the inbound logistic decision support model can be applied at other companies in different industries as well as long as the inbound flow is using road transport.

But the model developed here is not perfect and has a number of limitations. The following ones are identified by the researcher in this research:

- Only applicable for road transport;
- High number of parameter values needed for a reliable result;
- No indication on possible unexpected costs;
- The list of concepts that is included is never complete due to new developments.

To improve the model, there are two major options identified:

1. Develop an equation that describes the transport price per kilometer as a function of the distance and the type of truck that is used;
2. Base the decision not only on total cost or invested capital reduction, but also include criteria on flexibility and service level.

11.5 Results of the case study for Opole

To show the applicability of the inbound logistic decision support model, a case study was performed for the factory in Opole of Danone Baby Nutrition. After all suppliers had been mapped and thereby indicating the number of shipments per month, the average drop-size, the transport condition and whether or not it is a single-sourcing supplier, a total of 8 supplier-concept-combinations (SCC’s) were identified.

For each of these eight SCC’s, data has been collected and put into the inbound logistic decision support model. At first instance the results were not so promising so therefore it was decided to remove the large suppliers in the milk-run and cross-dock related SCC’s. By removing these suppliers, the result improved a little bit. However, none of the supplier-concept-combinations led to savings that are large enough to stimulate an implementation. The largest cost saving of €6600 was obtained by VMI SCC 3 that includes the large supplier in the northern part of the Netherlands.

Before a final conclusion on the results of the case study is drawn, Danone Baby Nutrition should (1) gather more accurate data, especially on the weighted pallet value of a supplier, and (2) verify the results of the transport cost calculation model with a tender.

Despite the disappointing results, this case study proofs that the decision support model is working and is useful in the assessment of possible savings on logistic costs and invested capital. So the design problem has been solved by constructing an elaborate model that has its roots in both the concepts and the models presented in literature.

11.6 Recommendations

In the conclusion already two recommendations have been made with respect to the results of the case study. The first recommendation was that more accurate data has to be collected before
a final conclusion on the case study can be drawn. The second one is that the transport cost calculation model has to be verified with real-life data from a tender.

Because the concepts included did not really lead to the expected cost savings, it might be useful to look for other concepts as well. By brainstorming and looking at different industries, other concepts will be found that can be included as well since the tools to construct these extra concept performance models are presented in this research report by means of the general calculation models. One possible direction is to search for concepts that include multiple factories instead of the single factory approach chosen in this research.

Though this model is only tested for one factory, so it is recommended to apply this model also to other factories because these factories will have a different supplier base. This supplier base might yield different, perhaps more positive, results but in this case it still holds that more accurate data should be collected than used in the case study here. After this last recommendation, an academic reflection is presented in the next section. In this reflection, the researcher critically evaluates the process presented in this research.

11.7 Academic reflection of conducted research on inbound logistics

In this last section the research is being evaluated with a critical point of view. This first starts with the approach that is chosen to identify available and suitable inbound logistic concepts for Danone Baby Nutrition. The current situation for Danone Baby Nutrition is described for both the supply chain and the inbound logistics procedure. Based on this description and four identified cost components the researcher started the exploration for inbound logistics concepts. Looking back at this procedure this could have been much more structured. A better approach would have been to perform a SWOT analysis\(^1\), identify a number of directions in which the inbound logistics can be improved and use these directions to search for concepts in literature and on the internet.

Despite the simple method of selecting the concepts, a better and more structure approach is used to develop the decision support model for the selected concepts. This approach is the strength of this research because the general calculation models have been taken from reliable literature sources. Using general calculation models leads to a strong connection between the concept performance assessment models because they are all build with the same blocks, the general calculation models. The fact that the concept specific models are based on the same basic calculations guarantees that any comparison between the concepts is justified as long as they have the same base case.

Still a small remark has to be made on the general calculation model that determines the transport cost. Since the researcher did not know that this would be the largest cost component when the general calculation models were developed, the attention paid to the development of this component did not match the importance. So this is an opportunity for further developing the decision support model.

While most attention went to the development of the decision support model, the process of how the model should be used is under addressed. So the implementation of the decision support model and the consequences of using the model could have been described in more detail.

So in the end it can be concluded that the approach taken to tackle the design problem has its opportunities to be improved, especially on the process of finding possible concepts and the consequences of using the decision support model. But the most important part of this research, developing the calculation models, is done in a structured and justified way.

\(^1\)This is a strategic planning method used to evaluate the Strengths, Weaknesses, Opportunities and Threats
Appendix A

An overview of decision-making models

• In Krumboltz et al. (1986) the DECIDES rational decision model is presented consisting of the following seven steps:
  1. Define the problem
  2. Establish an action plan
  3. Clarify values
  4. Identify alternatives
  5. Discover possible outcomes
  6. Eliminate alternatives systematically
  7. Start action

• Krabuanrat & Phelps (1998) state that the exact number of stages in a rational model of decision making and their contents vary, which are in the end summarized by the next five steps:
  1. A precise formulation of the problem
  2. Information search
  3. Listing of alternative solutions
  4. Evaluation of alternatives according to predetermined criteria
  5. Choice of solution

• According to Brim et al. (1962) the decision process consists of the six steps that do not necessarily have to be executed in this particular order:
  1. Identification of the problem
  2. Obtaining necessary information
  3. Production of possible solutions
  4. Evaluation of such solutions
  5. Selection of a strategy for performance
  6. Actual performance of an action or actions, and subsequent learning and revision
• **Tomer (1992)** states that eight steps have to be taken to achieve the best possible decision making in an organization:

1. Recognize the need for a decision: opportunities, problems and crises;
2. Decide about the decision process;
3. Diagnosis: What are the nature of the issues and problems?
4. Survey the organizational goals and the values implicated by the choice; determine decision criteria;
5. Search for existing alternatives and/or design new alternatives;
6. Evaluate the positive and negative consequences of the alternatives;
7. Selection: deliberate on and make a commitment to an alternative; and
8. Authorization

**Important to note from Tomer (1992):**

"It is not necessary that the steps be taken in precisely the sequence indicated, that every step be taken in all decision situations, or that the steps be taken only once."

• Two different decision-making models are presented in **Citroen (2011)** of which the first one is based on various literature resources resulting in the next seven steps:

1. The issue or problem is properly identified and the objectives of the decision are well defined by the decision-makers,
2. The decision-makers actively search for information on potential alternatives,
3. They carefully weigh the advantages and the disadvantages of these alternatives and the chances of success for each of them,
4. Even when a preliminary solution is in sight, new information or expert judgement is accepted, studied and analysed, even if it contradicts earlier ideas and preferences,
5. Before a final decision is made, positive and negative consequences of all alternatives are re-examined,
6. Provisions for implementation of the decision are prepared, (including a contingency plan that might be required if the implementation fails),
7. A procedure is defined for follow up of the decision to judge if the purpose has been achieved or has to be reconsidered. In some cases that can still be considered a rational process, not

**Later on Citroen developed a new model to use:**

1. Preparation: formulate issues, set objectives, timeline etc.
2. Analyses: review of the environment
3. Specification of the alternatives
4. Limiting alternatives and options
5. Assessment: Assess outcomes
6. Final decision and implementation
Appendix B

Traditional representation of Danone Baby Nutritions supply chain

In this appendix contains the traditional representations of the current (figure 3.4) and future supply chain (figure 3.5) in which manufacturing activities are indicated by rectangles and triangles represent storage. The arrows between these block illustrate goods transportation as also mentioned in the legend.

B.1 Current supply chain

Figure B.1: Traditional representation of the current European supply chain
B.2 Future supply chain

Figure B.2: Traditional representation of the future European supply chain
Appendix C

Incoterms

This appendix contains information about the incoterms used in this research report. First an explanation of these incoterm, DDP and EXW, will be presented that is directly taken from International Chamber of Commerce (ICC) (n.d.). In the end a wallchart that illustrates all incoterms is depicted.

C.1 DDP: Delivered Duty Paid

"Delivered duty paid" means that the seller delivers the goods to the buyer, cleared for import, and not unloaded from any arriving means of transport at the named place of destination. The seller has to bear all costs and risks involved in bringing the goods thereto including, where applicable, any "duty" (which term includes the responsibility for and the risks of carrying out of customs formalities and the payment of formalities, customs duties, taxes and other charges) for import in the country of destination.

Whilst the EXW term (see next section) represents the minimum obligation for the seller, DDP represents the maximum obligation.

This term should not be used if the seller is unable directly or indirectly to obtain the import license.

However, if the parties wish to exclude from the seller's obligations some of the costs payable upon import of the goods (such as value-added tax: VAT), this should be made clear by adding explicit wording of this effect in the contract of sale.

If the parties wish the buyer to bear all risks and costs of the import, the DDU (Delivered Duty Unpaid) term should be used.

This term may be used irrespective of the mode of transport but when delivery is to take place in the port of destination on board the vessel or in the quay (wharf), the DES (Delivered Ex Ship) or DEQ (Delivered Ex Quay) terms should be used.

C.2 EXW: EX Works

"Ex works" means that the seller delivers when he places the goods at the disposal of the buyer at the seller's premises or another named place (i.e. works, factory, warehouse, etc.) not cleared for export and not loaded on any collecting vehicle.

This term thus represents the minimum obligation for the seller, and the buyer has to bear all
costs and risks involved in taking the goods from the seller's premises.

However, if the parties wish the seller to be responsible for the loading of the goods on departure and to bear the risks and all costs of such loading, this should be made clear by adding explicit wording to this effect in the contract of sale. This term should not be used when the buyer cannot carry out the export formalities directly or indirectly. In such circumstances, the FCA (Free Carrier) term should be used, provided that the seller agrees that he will load at his cost and risk.

C.3 Incoterms wallchart

This wallchart is taken from International Chamber of Commerce (ICC) (1999), due the size it had to be split into two parts on two pages.
Group C | Main carriage paid by seller

Under C Terms the seller arranges and pays for the main carriage but without assuming the risk of the main carriage.

**CFR** (Cost and Freight) - Cost to a nominated port of destination.
- **Risk:** Carriage to be arranged by the seller.
- **Costs:** Cost of carriage to be paid by the seller.
- **Insurance:** Insurance to be arranged by the buyer.

**CIF** (Cost, Insurance and Freight) - Cost, insurance and freight to a nominated port of destination.
- **Risk:** Carriage and insurance to be arranged by the seller.
- **Costs:** Cost of carriage and insurance to be paid by the seller.
- **Insurance:** Insurance to be arranged by the seller.

**CPT** (Carriage Paid To) - Carriage paid to a nominated place of destination.
- **Risk:** Risk transfer from the seller to the buyer when the goods are placed at the disposal of the carrier.
- **Costs:** Cost transfer from the seller to the buyer when the goods are placed at the disposal of the carrier.

**CIP** (Carriage and Insurance Paid To) - Carriage paid to a nominated place of destination with insurance.
- **Risk:** Risk transfer from the seller to the buyer when the goods are placed at the disposal of the carrier.
- **Costs:** Cost transfer from the seller to the buyer when the goods are placed at the disposal of the carrier.

Group D | Arrival

Under D Terms the seller’s cost/risk is maximised because he must make the goods available upon arrival at the agreed destination.

**DAF** (Delivered At Frontier) - Goods delivered to frontier.
- **Risk:** Carriage to be arranged by the seller.
- **Costs:** Cost transfer from the seller to the buyer when the goods reach the frontier.

**DES** (Delivered Ex Ship) - Goods delivered to ship.
- **Risk:** Risk transfer from the seller to the buyer when the goods are placed at the disposal of the buyer on board the ship.
- **Costs:** Cost transfer from the seller to the buyer when the goods are placed at the disposal of the buyer on board the ship.

**DDU** (Delivered Duty Unpaid) - Goods delivered to the buyer.
- **Risk:** Carriage to be arranged by the seller.
- **Costs:** Cost transfer from the seller to the buyer when the goods are placed at the disposal of the buyer.

**DDP** (Delivered Duty Paid) - Goods delivered to the buyer.
- **Risk:** Risk transfer from the seller to the buyer when the goods are placed at the disposal of the buyer.
- **Costs:** Cost transfer from the seller to the buyer when the goods are placed at the disposal of the buyer.

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Incoterms 2000 will not apply unless incorporated into the contract of sale by mutual agreement. Any contract is governed by Incoterms 2000.

Incorporation of Incoterms 2000 into a contract of sale is an optional matter and does not alter the legal obligations of the parties. Incoterms 2000 are ICC’s standard definitions of trade terms and are internationally recognized as indispensable evidence of the buyer’s and seller’s responsibilities for delivery under a sales contract.
Appendix D

Average inventory calculation with overlap

In this appendix the equations used to calculate average inventory levels are derived for the situation in which the replenishment actions are overlapping to ensure a continuous flow of goods with a quality control. The symbols that will be used are illustrated in D.1. Based on this figure the area under the graph will be calculated for two different situations:

1. \( t_o \leq t_{qc} \)
2. \( t_o > t_{qc} \)

So for each of these situations the area under the graph will be determined what leads to the average inventory. In the end these two equations will be combined. The first situation that will be is the one with \( t_o \leq t_{qc} \).

![Diagram showing overlapping replenishment actions](image)

Figure D.1: Overlapping replenishment actions

With:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q )</td>
<td>Quantity ordered</td>
<td>Euro pallet</td>
</tr>
<tr>
<td>( t_{qc} )</td>
<td>Duration of the quality control</td>
<td>Day</td>
</tr>
<tr>
<td>( t_p )</td>
<td>Production time per delivered batch</td>
<td>Day</td>
</tr>
<tr>
<td>( t_o )</td>
<td>Overlap</td>
<td>Day</td>
</tr>
</tbody>
</table>
D.1 Average inventory level with $t_o \leq t_{qc}$

The first situation for which the average inventory level will be calculated is the one where the overlap is smaller or equal to the duration of the quality control. When looking at the total inventory level of the situation where the overlap is small than the quality control duration it result in figure D.2.

![Figure D.2: Sections of the total inventory curve in case of overlap with $t_o < t_{qc}$](image)

In this graph three different stage can be defined and for each of these stages the area $A_i$ under the graph will be determined after which the average inventory of a cycle can be calculated by:

$$I = \frac{\sum A_i}{\sum t_i} \quad (D.1)$$

First the section that indicates the overlap will be described.

D.1.1 Area of section 1: Overlap

In the first section overlap occurs between two successive replenishment actions leading to the following formula that described the inventory level:

$$I_1 = Q + \frac{Q}{t_p} t_o - \frac{Q}{t_p} x$$

Where the new replenishment arrives at $x = 0$. The surface under this curve can be calculated by using the following integral:

$$\int_0^{t_o} Q + \frac{Q}{t_p} t_o - \frac{Q}{t_p} x \, dx = \left[ Q \cdot x + \frac{Q}{t_p} t_o \cdot x - \frac{Q}{2t_p} x^2 \right]_0^{t_o} = Q \cdot t_o + \frac{Q \cdot t_o^2}{2t_p} - \frac{Q \cdot t_o^2}{2t_p} = Q \cdot t_o + \frac{Q \cdot t_o^2}{2t_p}$$

So in the end the total surface can be calculated by:

$$A_1 = Q \cdot t_o + \frac{Q \cdot t_o^2}{2t_p}$$

(D.4)

D.1.2 Area of section 2: Quality Control

When the production stops the overlap is finished as well, but the new batch is still in quarantine for the quality control. The equation for this inventory level is constant:

$$I_2 = Q$$

(D.5)
Resulting in the following integral:

\[ \int_{t_o}^{t_{qc}} Q \, dx = [Qx]_t^{t_{qc}} = Q \cdot (t_{qc} - t_o) \]  

(D.6)

And thus the area can be computed by:

\[ A_2 = Q \cdot t_{qc} - Q \cdot t_o \]  

(D.7)

When a constant rate has to be fed into the production \( t_o \) will be equal to \( t_{qc} \) leading to \( A_2 = 0 \). So in this situation only sections 1 and 3 will remain.

### D.1.3 Area of section 3: Production

Finally the production is started thereby reducing the stock. The production is started at \( x = 0 \) resulting in the following equation for the curve:

\[ I_3 = Q - \frac{Q}{t_p} x \]  

(D.8)

Leading to this next equation for the area:

\[ \int_{0}^{t_{p}-t_o} Q \div \frac{Q}{t_p} \, dx = [Q \cdot x - \frac{Q}{2t_p} x^2]_0^{t_{p}-t_o} = Q \cdot (t_p - t_o) - \frac{Q}{2t_p} (t_p - t_o)^2 = \frac{Q}{2t_p} - \frac{Q \cdot t_o^2}{2t_p} \]  

(D.9)

This results in:

\[ A_3 = \frac{Q}{2t_p} - \frac{Q \cdot t_o^2}{2t_p} \]  

(D.10)

### D.1.4 Average inventory

To determine the average inventory in case there is an overlap between the replenishment action again equation D.1 is used. Filling in equations D.4, D.7 and D.10 results in:

\[ \bar{I} = \frac{[Q \cdot t_o + \frac{Q \cdot t_o^2}{2t_p}]}{Q \cdot (t_{qc} - t_o)} + \frac{[Q \cdot (t_{qc} - t_o)]}{2t_p} \]  

(D.11)

And this is equal to:

\[ \bar{I} = \frac{Q \cdot t_{qc} + \frac{Q \cdot t_p}{2}}{t_p + t_{qc} - t_o} \]  

(D.12)

And in case of \( t_o = t_{qc} \) this can be simplified to:

\[ \bar{I} = \frac{Q \cdot t_{qc} + \frac{Q \cdot t_p}{2}}{t_p} = \frac{Q \cdot t_o + \frac{Q \cdot t_p}{2}}{t_p} \]  

(D.13)

The next situation that will be calculated is the one in which \( t_o > t_{qc} \).

### D.2 Average inventory level with \( t_o > t_{qc} \)

When the goods arrive more than \( t_{qc} \) days before production a different situation exists and this leads to the graphs presented in figure D.3. Figure D.3a represents the individual replenishment quantities whereas figure D.3b displays the total inventory level. From these figures it can be seen that this is in fact a lifted saw-tooth diagram.
Figure D.3: The effect of replenishment actions with \( t_o > t_{qc} \)

The function that holds here is (where the replenishment action is performed on \( x = 0 \)):

\[
I = Q + \frac{Q}{t_p} t_o - \frac{Q}{t_p} x
\]  
(D.14)

The duration between the replenishment actions will be equal to \( t_p \) and therefore the following integral has to be solved to calculated the area under the inventory level graph:

\[
A = \int_0^{t_p} Q + \frac{Q}{t_p} t_o - \frac{Q}{t_p} x \, dx = \left[ Q \cdot x + \frac{Q}{t_p} t_o \cdot x - \frac{Q}{2t_p} x^2 \right]_0^{t_p}
\]

\[
= Q \cdot t_p + Q \cdot t_o - \frac{Q}{2} \cdot t_p = \frac{Q}{2} t_p + Q \cdot t_o
\]  
(D.15)

So in the end the average inventory can be calculated by:

\[
\bar{I} = \frac{Q \cdot t_o + \frac{Q}{2} t_p}{t_p}
\]  
(D.16)

**D.3 Average inventory in all situations**

In the previous two section three different scenarios have been presented for which the average inventory was calculated. This led to the next three equations:

- \( t_o < t_{qc} \)
  \[
  \bar{I} = \frac{Q \cdot t_{qc} + \frac{Q}{2} t_p}{t_p + t_{qc} - t_o}
  \]  
(D.17)

- \( t_o = t_{qc} \)
  \[
  \bar{I} = \frac{Q \cdot t_{qc} + \frac{Q}{2} t_p}{t_p} = \frac{Q \cdot t_o + \frac{Q}{2} t_p}{t_p}
  \]  
(D.18)

- \( t_o > t_{qc} \)
  \[
  \bar{I} = \frac{Q \cdot t_o + \frac{Q}{2} t_p}{t_p}
  \]  
(D.19)

Based on these formulas it can be seen that they have a general structure that can be combined with this mathematical equation:

\[
\bar{I} = \frac{Q \cdot \left[ t_{qc}, t_o \right] + \frac{Q}{2} t_p}{t_p + \left[ 0, t_{qc} - t_o \right]}
\]  
(D.20)
Or in a more general form that can be used in Microsoft Excel:

$$\bar{I} = \frac{Q \cdot \max(t_{qc}, t_o) + \frac{Q}{2} t_p}{t_p + \max(0, t_{qc} - t_o)}$$

(D.21)

When this equation is used for the situation with $t_{qc} = t_o = 0$ it results in:

$$\bar{I} = \frac{Q \cdot 0 + \frac{Q}{2} t_p}{t_p + 0} = \frac{Q}{2}$$

(D.22)

And this equation is the one that is used to calculate the average inventory of a normal saw-tooth diagram.
Appendix E

Input values of sensitivity analyses

An overview can be found here of the values used to perform the sensitivity analyses.

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Appendix F

Digital inbound logistic decision support model and research report

On the CD-rom attached below the reader can find the following documents:

- A digital version of this research report (PDF-format)
- A blank version of the inbound logistics decision support model
- A version of the inbound logistics decision support model containing the data of the case study for Opole
Appendix G

Data overview of all mapped suppliers for Opole

In this appendix, the data of the suppliers is presented in two different sections. The first section will contain information about the shipments while the second sections will contain information on the suppliers location.

G.1 Shipment data

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<th>Yearly deliveries</th>
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G.2 Location data

Because one supplier can have multiple shipping location, more than one address can be presented in the following tables on the shipping addresses.

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As a result of the shift in focus from outbound to inbound logistics, a decision support model is developed in this research report. The effects of four widely used logistic concepts can be quantified with respect to cost and invested capital by using this model. Independent of the industry, the developed model can be applied by every company to discover the potentials that exists in optimizing road-based inbound logistics.