THE ECONOMIC PERFORMANCES OF SUPPLY CHAIN(S) SERVED BY THE MEGA FREIGHT TRANSPORT VEHICLES

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Abstract: This paper deals with the economic performances of supply chain(s) served by different including the mega freight transport vehicles. These performances are considered as a dimension of the supply chain's sustainability together with the infrastructural, technical/technological, operational, environmental, and social performances. The supply chain(s) consists of the spoke and hub supplier(s) and the hub and spoke consumer(s) of goods/freight shipments. The economic performances include the inventory, handling, and transport cost of goods/freight shipments processed in the chain(s). The analytical model is developed for estimating the above-mentioned economic performances of the generic configuration of supply chain(s) operating according to the specified scenario(s) under given conditions. Then, the model is applied to the intercontinental supply chain exclusively served by the conventional and mega container ships aiming at investigating their effects/impacts on the chain's economic performances.

Key words*: supply chain(s), economic performances, analytical models, mega container ships*

1 Introduction

A general definitions of supply chain states that it is: "the movement of materials as they flow from their source to the end customer including purchasing, manufacturing, warehousing, transportation, customer service, demand and supply planning, and Supply Chain management" (http://www.supplychaindefinitions.com/). In this paper, the supply chain is considered as the physical network, which produces, handles, transports, and receives goods/freight shipments consolidated into TEUs (Twenty Foot Equivalent Unit(s)) between their ultimate suppliers and customers. These can be the large production/consumption plants, distribution centers, sea-ports, airports, large surface modal (rail, road), and intermodal (rail/road/barge) terminals. They usually generate and attract rather substantive flows of these (consolidated) goods/freight shipments and as such operate as the hub nodes of the global (continental and intercontinental) freight transport network(s). In many cases, these substantive flows between particular hub nodes are transported by larger including the mega freight transport vehicles. These mega vehicles are easily recognizable within each transport mode: road – mega trucks, rail/intermodal - long freight trains, air - large cargo aircraft, and sea – large container ships. (http://www.investopedia.com/terms/s/supplychain.asp; http://en.wikipedia.org/wiki/Supply_chain.

This paper deals with the economic performances of supply chain(s), which are served by different including the mega freight transport vehicles. In addition to this, the paper consists of three other sections. Section 2 explains the concept and develops the analytical model for estimating the economic performances of a given supply chain(s). Section 3 presents an application of the proposed model. The last section summarises some conclusions.

2 The Concept and Model of Economic Performances of Supply Chain(s)

2.1. The concept

In general, the performances of supply chain(s) are considered as its inherent ability to deliver goods/freight shipments between their ultimate suppliers/senders and ultimate customers/receivers under given conditions, usually as planned, i.e., generally efficiently, effectively, and safely. Consequently, as at the similar systems, the performances of supply chains can be classified as infrastructural, technical/technological, operational, economic, environmental, and social (Janic, 2014). Specifically, the economic performances can generally be the chain's inventory, handling, and transportation cost of the goods/freight shipments.

2.2. Some previous research

The previous research on dealing directly or indirectly with particular performances of supply chains has been substantive. The research closely related to that presented in this paper addresses the role and influence of transport operations on the entire performances of supply chain(s).

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This has mainly dealt with understanding the relationships between the transport and logistics operations and possible improvements through i) the goods/freight shipment(s) delivery speed, quality of service, operating costs, use of facilities and equipment, and savings energy (Tseng et al., 2005), ii) modelling performances of different spatial and operational configurations of the goods/freight collection/distribution networks (Janic 2005; 2014), and iii) understanding the potential interactions between location of European manufacturing industry, related services, and logistics and freight transport (EC, 1999). In addition, the research on an explicit investigation of the effects/impacts of the mega freight vehicles on the performances of supply chains has been scarce. An exception has been elaboration of the infrastructural, technical/technological, operational, economic, environmental, and social performances of these (mega) vehicles such as long intermodal freight trains, road mega trucks, large freight/cargo aircraft, and large container ships on the case-by-case, i.e., vehicle-by-vehicle, basis (Janic, 2014). Consequently, this paper intends to partially fill in this gap by considering the effects/impacts of mega vehicles on the economic performances of supply chain(s). .

2.3. The Objectives and Assumptions

The objectives of the paper are to develop an analytical model for estimating the economic performances of a given supply chain(s) served by different including the mega freight transport vehicles. The model is based on the following assumptions (Daganzo, 2005; Janic, 2005):

- The hub supplier of a given supply chain(s) is ultimately the production location, i.e., origin, of the goods/freight shipments; the hub customer is ultimately their consumption location, i.e., destination;
- The chain(s)'s production/consumption cycle during the specified period of time satisfies the series of successive orders of goods/freight shipments to be transported between the hub supplier and the hub customer exclusively by the different vehicle fleets including the mega one;
- The size of a goods/freight shipment(s) is always less than or at most equal to the payload capacity of a given vehicle serving the chain(s);
- The fleet(s) serving the supply chain(s) consists of vehicles of the same size/payload capacity operating with the same load factor; and
- Exclusive use of a given vehicle fleet implies the "all-or-nothing principle" of serving goods/freight shipments within the chain.

2.5. Generic Configuration of a Supply Chain(s)

The generic configuration of a supply chain(s) served by any category of the freight transport vehicles is represented as the H-S (Hub-and-Spoke) transport network whose main nodes are the hub supplier(s) and the hub customer(s) connected by the transport link(s) between them as shown on Figure 1 (a, b). The spokes 'feeding' the hub supplier(s) and those 'fed' by the hub customer(s) are also shown. As can be seen, the inventories of goods/freight shipments take place at the hub supplier(s), the hub customer(s), and along the route between them. Figure 1a shows the case a) of exclusive and Figure 1b the case b) of simultaneous collecting and loading of goods/freight shipments at the hub supplier(s), and their exclusive unloading and distributing at the hub customer(s), respectively. 'Exclusivity' implies that the entire shipment is collected before starting its loading, and the entire shipment is unloaded before starting its distribution. 'Simultaneously' implies that both collecting and loading of goods/freight shipment(s) on the one end and its unloading and distribution on the other end of the chain can be partially or fully carried out at the same time. Is such way, it is possible to manage the inventories of goods/freight shipments and related costs.

2.6 Basic Structure of the Model

The economic performances of a given supply chain are considered to be the i) inventory, ii) handling, and iii) transport a) the total and b) the average cost of goods/freight shipment(s) served within the chain. If the size of goods/freight shipment corresponds to the vehicle payload capacity, these costs are determined as follows:
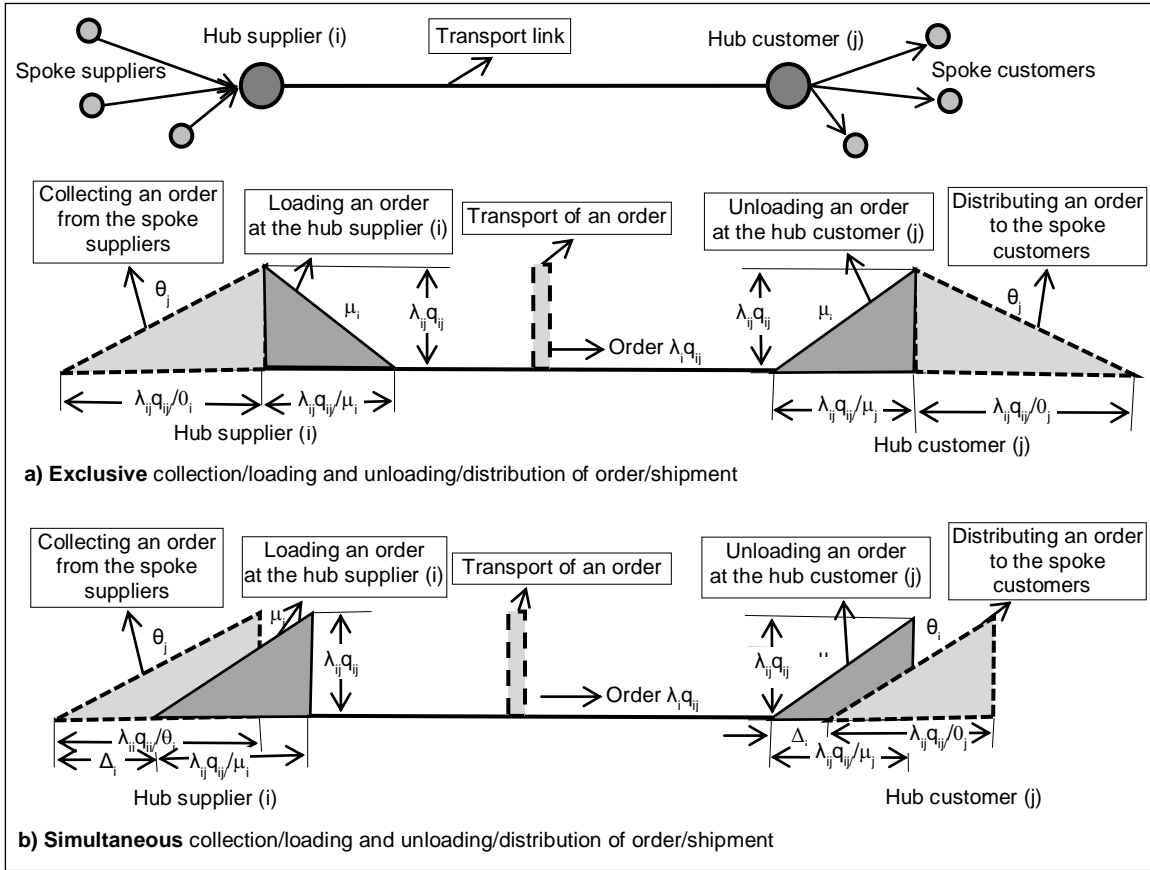
Simplified scheme of the generic configuration of supply chain(s) (Janic, 2014)

a) Inventory cost (€ or $US)

$$C_{ij/INV}(\lambda_{ij}q_{ij}) = IT_i(\lambda_{ij}q_{ij}) * \alpha_i + (\lambda_{ij}q_{ij}) * \frac{d_{ij}}{s_{ij} * v_{ij}(d_{ij})} * \alpha_{ij} + IT_j(\lambda_{ij}q_{ij}) * \alpha_j \qquad (1)$$

The first and third term in Eq. 1 represent the inventory cost of a goods/freight shipment at the hub supplier *(i)* and at the hub customer *(j)*, respectively. The second term represents the inventory, i.e., the shipment's cost of time while in transportation between the hubs *(i)* and *(j)*. From Figure 1, the goods/freight shipment inventory time in Eq. 1 at the hubs *(i)* and *(j)*, respectively, is determined as follows:

$$IT_i(\lambda_{ij}q_{ij}) = \begin{cases} \dfrac{1}{2}(\lambda_{ij}q_{ij})^2 \left[\dfrac{1}{r_i\theta_i} + \dfrac{1}{p_i\mu_i} \right] & if \quad a) \\[4mm] \max\left\{ 0; (\lambda_{ij}q_{ij})^2 \left(\dfrac{1}{p_i\mu_i} - \dfrac{1}{2r_i\theta_i} \right) + (\lambda_{ij}q_{ij})\Delta_i \right\} & if \quad b) \end{cases} \qquad (2a)$$

and analogously

$$IT_j(\lambda_{ij}q_{ij}) = \begin{cases} \dfrac{1}{2}(\lambda_{ij}q_{ij})^2\left[\dfrac{1}{r_j\theta_j} + \dfrac{1}{p_j\mu_j}\right] & if \;\; a) \\[3mm] \max\left\{0;(\lambda_{ij}q_{ij})^2\left(\dfrac{1}{p_j\mu_j} - \dfrac{1}{2r_j\theta_j}\right) + (\lambda_{ij}q_{ij})\Delta_j\right\} & if \;\; b) \end{cases} \tag{2b}$$

b) Handling and transport cost (€ or $US)

$$C_{ij/H-TRA}(\lambda_{ij}q_{ij}) = c_i * (\lambda_{ij}q_{ij}) + c_{ij}(\lambda_{ij}q_{ij}) * (\lambda_{ij}q_{ij}) * d_{ij} + c_j * (\lambda_{ij}q_{ij}) \tag{3}$$

c) Total (inventory + handling + transport) cost (€ or $US)

$$C_{ij}(\lambda_{ij}q_{ij}) = C_{ij/INV}(\lambda_{ij}q_{ij}) + C_{ij/H-TRA}(\lambda_{ij}q_{ij}) \tag{4}$$

d) Average total cost (€ or $US/TEU-km or ton-km)

$$\overline{c}_{ij}(\lambda_{ij}q_{ij}) = C_{ij}(\lambda_{ij}q_{ij}) / [(\lambda_{ij}q_{ij}) * d_{ij}] \tag{5}$$

where

λ_{ij}, q_{ij} is the average load factor and the payload capacity, respectively, of a vehicles serving the chain *(ij)* (tons, m³, or TEUs per vehicle);

Δ_i, Δ_j is the time between starting vehicle's loading at the hub supplier *(i)* and unloading at the hub customer *(j)*, respectively (TU);

d_{ij} is the length of transport route between the hubs *(i)* and *(j)* (km);

$v_{ij}(d_{ij})$ is the vehicle's average (planned) operating speed on the route *(d$_{ij}$)* (km/TU or kts (knots); 1 kts = 1nm/h; nm – nautical mile = 1.852km));

μ_i, μ_j is the loading and unloading rate of a vehicle at the hubs *(i)* and *(j)*, respectively (tons, m³ or TEU/TU);

p_i, p_j is the proportion of vehicle's loading and unloading rate used at the hubs *(i)* and *(j)*, respectively ($p_{il}, p_{jl} \leq 1.0$);

s_{ij} is the portion of maintained vehicle's average planned operating speed on the route *(d$_{ij}$)* ($s_{ij} \leq 1.0$)

θ_i, θ_j is the rate of collecting and distributing goods/freight shipments at the hubs *(i)* and *(j)*, respectively (tons, m³ or TEU/TU);

r_i, r_j is the proportion of rate of collecting and distributing goods/freight shipments used at the hubs *(i)* and *(j)*, respectively ($r_i, r_j \leq 1.0$);

c_i, c_j is the handling (loading/unloading/transhipment) cost of a goods/freight shipment at the hubs *(i)* and *(j)*, respectively (€/(ton, m³, or TEU)); and

$\alpha_i, \alpha_{ij}, \alpha_j$ is the cost of goods/freight shipment inventory time while at the hub *(i)*, in transportation, and at the hub *(j)*, respectively (€/(ton or m³ or TEU)/h or day).

By replacing the shipment size *(λ$_{ij}$q$_{ij}$)* by the quantity of goods/freight *(Q$_{ij}$)* generated during the chain's production/consumption cycle, the corresponding economic performances can be estimated similarly from Eqs. 1-5. In addition, these Eqs. indicate that the goods/freight shipment inventory time and related cost could be compromised in any handling phase in the chain, i.e., during collecting, loading, transporting, unloading, and distributing.

3. Application of the Model of Economic Performances of the Supply Chain(s)

3.1. The Case

The above mentioned model of economic performances is applied to the case of supply chain between North Europe and Far East Asia served by the liner container shipping. The hub supplier is assumed to be the port of Rotterdam – APM Terminals Rotterdam (The Netherlands) and the hub customer is assumed to be the port of Shanghai – Yangshan Deepwater Port Phases 1/2 or 3/4 (People Republic of China). Currently, this is one of the world's busiest chains (sea trading routes)[2] sharing about 70% of the total trading volumes between Europe and Asia. The container terminals at both ports of the given route enable access and operation of the large container ships including the currently largest Triple E Maersk. The collection and distribution of goods/freight shipments (TEUs) at both ports is carried out by rail/intermodal, road, inland waterway (barge), and feeder (including short-sea) vessel transport modes (Zhang et al, 2009).

Fig. 2
Simplified scheme of geography of the given supply chain – the liner shipping
route Rotterdam – Shanghai (http://www.ship.gr/news6/hanjin28.htm)

Two scenarios of operating the given chain (route) are considered: the first implies an exclusive use of container ships of the capacity of 4000 TEU (or the current Panamax) and the other an exclusive use of container ships of the capacity of 18000 TEU (i.e., Neo Panamax represented by Triple E class ship started operations by Maersk in the year 2013) The length and width (beam) of the container ships, similarly as their above-mentioned capacity, are specified by design as shown in on Figure 3 (http://www.worldslargestship.com/).
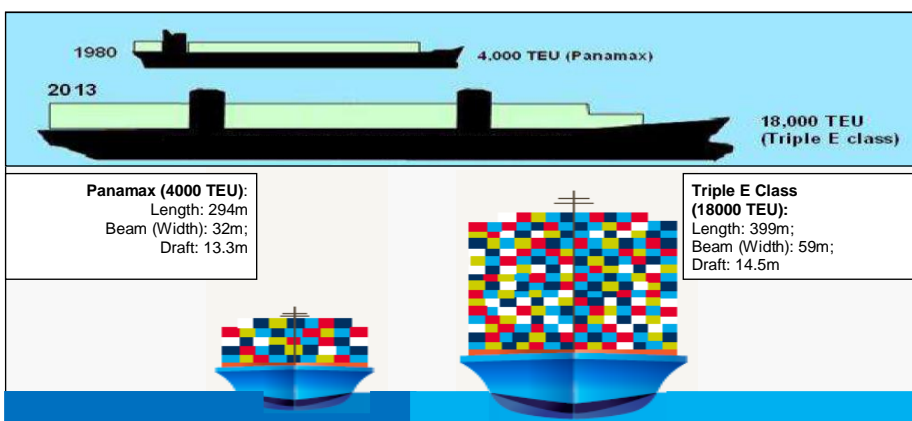

Fig. 3
Scheme of the container ships used in the given supply chain (PR, 2011;
http://en.wikipedia.org/wiki/Container_ship*)*

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[2] This chain (sea trading route) included in the WCI (World Container Index) together with other 10 most voluminous world's container chains (sea trading routes) shares about 35% of their total volumes (TEUs) (http://www.worldcontainerindex.com/).

In both scenarios, the container ships are assumed to operate at the typical slow steaming speed of 20 kts (knots) and the supper slow steaming speed of 15 kts (1kt = 1nm/h; nm – nautical mile) (SCG, 2013). In addition, only direct transportation of the containerized goods/freight shipments in the single direction of the chain is considered.

3.2. Input Data

The input data for application of the proposed models to the given supply chain are collected from the case itself and the other different sources and given in Table 1.

Table 1

Input data for application of the models of performances to the given supply chain – liner shipping route Rotterdam (The Netherlands) – Shanghai (China)

Input variable	Notation/Unit	Value
• Container ship capacity	q_{ij} (TEU/ship)	4000; 18000
• Container ship length	L_{ij}(m)/q_{ij}(TEU/ship)	294 (4000); 399 (18000)
• Container ship beam (width)	w_{ij}(m)/q_{ij} (TEU/ship)	32 (4000); 59 (18000)
• Container ship load factor	λ_{ij}	0.80 (4000); 0.80 (18000)
• Collection rate of containers at the hub supplier port	θ_i (TEU/day)	1100
• Proportion of used collection rate of containers at the hub supplier port	r_i	1.0
• Distribution rate of containers at the hub customer port	θ_j (TEU/day)	1100
• Proportion of used distribution rate of containers at the hub customer port	r_j	1.0
• Loading rate of containers at the hub supplier port	μ_i (TEU/h)	92 (3-4 cranes)/ 215 (7-8 cranes)
• Proportion of used loading rate of containers at the hub supplier port	p_i	1.0
• Unloading rate of containers at the hub customer port	μ_j (TEU/h)	94 (3-4 cranes)/ 215 (7-8 cranes)
• Proportion of used unloading rate of containers at the hub customer port	p_j	1.0
• Time between starting colleting and loading containers at the hub supplier port	Δ_i (day(s))	1
• Time between starting unloading and distributing containers at the hub consumer port	Δ_j (day(s))	1
• Operating distance between the hub ports	d_{ij} (nm)	10525
• Average operating speed of container ship	v_{ij} (kts)	20 (Slow steaming) 15 (Super slow steaming)
• Portion of the maintained average ship's operating speed	s_{ij}	1.0
• Container inventory cost at the hub ports	α_i, α_j (€/TEU-day)	124; 124
• Container cost of time in transportation	α_{ij} (€/TEU-day)	10.6
• Container handling cost at the hub supplier port	c_i (€/TEU)	185
• Container handling cost at the hub customer port	c_j (€/TEU)	58
• Container ship operating cost	c_{ij} (€cents/TEU-nm)/ v_{ij}(kts)/q_{ij}(TEU/ship)	9.90/20; 5.49/15 (4000) 2.01/20; 1.13/15 (18000)

The number of containers (TEU) per chains' production/consumption cycle of duration of one year is determined by assuming the service frequency by the Triple E class ships of 1dep/week, the Panamax class ships of 5depts/week, and the average load factor of both ship classes of 0.80. These give the total annual number of 748800 TEUs to be transported within the chain according the specified scenarios implying using exclusively one class of ships under given conditions. This is, however, only about one sixth of the total annual number of TEUs transported within the chain (http://www.worldcontainerindex.com/).

The rates of collection and distribution of goods/freight shipments (TEUs) are set up regarding the service schedule of different inland transport modes serving the ports (terminals) at both ends of the chain (route) (Zhang et al., 2009). The container loading and unloading rates are set up based on the empirical evidence from both ports/terminals. Two cases are considered: first, both categories of ships are loaded/unloaded by using 3-4 cranes simultaneously (Mongelluzzo, 2013); second, the Triple E class ships are loaded/unloaded by up to seven to eight cranes simultaneously at both ends of the chain (route) (SCG, 2013). All selected crane rates are considered to be fully operational over the period of 24h/day. As well, the shipments are assumed to be completely collected at the hub supplier port before being loaded and completely unloaded at the hub consumer port before being distributed further.

The time between docking and starting loading and unloading of ships at the corresponding ports is chosen as an illustration (This could be reasonable regarding the administrative procedures to be carried out after the ship(s) docks at berths).

The ships are assumed to operate along the route at the constant (slow or super slow steaming) speed(s) without its substantive variations (http://www.sea-distances.org/). This implies that all transport services are assumed to be perfectly reliable, i.e., without delays along the route and consequently at the destination. .

The inventory cost of container(s) during collection and loading at the hub supplier port (Rotterdam) and unloading and distribution at the hub customer port (Shanghai) is estimated based on the average retail value of goods in containers and typical share of the inventory cost (25%) in that value (REM Associates, 2014; Rodrigue, 2013). The cost of container time during transportation is considered as an average for the goods/freight shipments carried out by the sea transport mode (VTI, 2013).

The handling cost of containers at both port terminals is based on the empirical evidence (EC, 2009). The cost of container ship(s) operating on open sea are estimated respecting the effects of cruising/operating speed(s) on the fuel consumption, fuel price (assumed constant), and the share of fuel cost in the total ship's operating costs (Cullinane and Khanna, 2000; Davidson, 2014; Sys et al., 2008; Stopford, 2003).

3.3. Analysis of Results

The results from application of the model of economic performances to the given case of supply chain based on the input data in Table 1 are shown in Figures 4. Figure 4a show that**,** the relative terms, if exclusively transport cost are considered, the mega ship(s) is for about 5 times more cost efficient than its smaller counterpart(s), while operating on open sea at either steaming speed (20kts or 15kts). This unit cost difference appears to be in line with differences in the ships' size/capacity, thus confirming existence of the substantive economies of scale of the mega container ship(s) under given conditions. Figure 4b shows the total chain's average cost consisting of the inventory and handling cost of collecting/loading and unloading/distributing containers (TEUs) at hub ports, their time cost in transportation, and transport cost. In such case, if the fleet of smaller ships serves the chain, it will be more cost efficient (for about 52% and 79%) than if being served by the fleet of mega ships at either the slow (20kts) and super slow (15kts) steaming speed, respectively. Speeding up of the loading and unloading of the fleet of mega ships at the hub ports decreases this still positive difference for the fleet of smaller ships to about 30% (at slow) and 52% (at super slow) steaming speed. In addition, reducing the steaming speed decreases the chain's average costs much more when served by the fleet of smaller than by the fleet of mega ships, i.e., for about 24% and 1-1.5%, respectively.

Figure 4c shows that the chain's total average cost decrease by excluding the inventory cost during collecting and distributing containers (TEUs) at the hub ports. This time the chain becomes more cost efficient when served by the fleet of mega ships operating at the slow steaming speed (20kts) (for about 14%). However, the chain becomes less cost efficient (for about 8%) if the fleet of mega ships serves it at the super slow steaming speed (15kts). In case of speeding up the loading and unloading of mega ships at the hub ports, the chain's inventory cost substantively decreases causing decreasing of the total average cost.

Consequently, in this of fast loading/unloading, if all other cost remain unchanged, the chain served by the fleet of mega ships operating at the slow and super slow steaming speed(s) becomes much more cost efficient (62% and 34%, respectively) than in the case when being served by the fleet of smaller counterparts.

Table 2 gives the structure of the chain's average cost when the inventory cost during collecting/loading and unloading/distribution of containers (TEUs) at the hub ports are included. As can be seen, the share of this (inventory) cost is much lower and the share of transport cost is much higher in the total cost if the chain is served by the fleet of smaller than that of mega ships, independently on their operating speed(s). In any case, reducing the operating speed contributes to increasing of the share of inventory cost on the account of the share of transport cost. Speeding up loading/unloading of the mega ships at the hub ports reduces very little the share of inventory cost compared to that under common loading/unloading .rate(s). Table 3 gives the structure
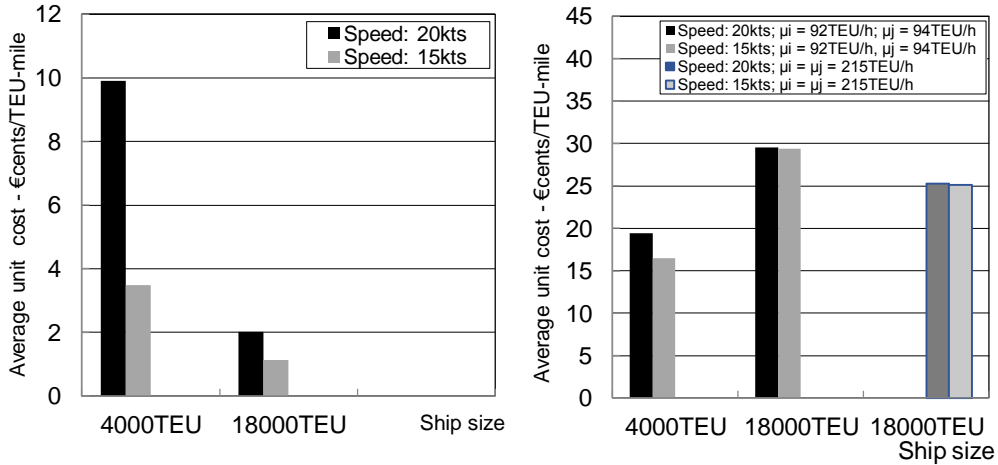
a) Average transport (ship) operating cost

b) Average chain's cost including the inventory cost during collecting/loading and unloading /distributing containers (TEUs)
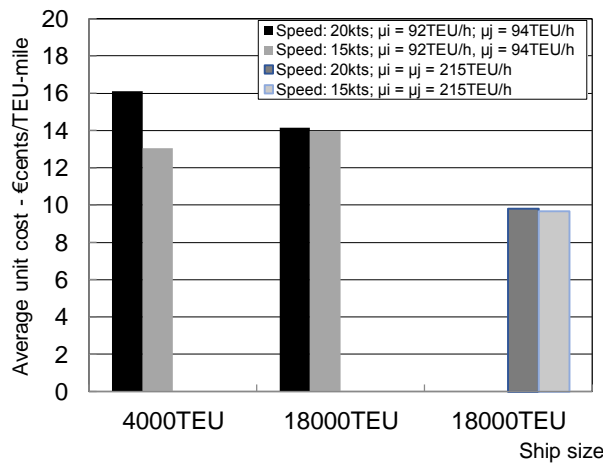
c) Average chain's cost including only the inventory cost during loading and unloading containers (TEUs)

Fig. 4
Economic performances of the given supply chain

Table 2
Structure of the total cost of given supply chain: - The inventory cost
during <u>collecting/loading + unloading/distributing</u> containers (TEUs) included

Operating characteristics	Container ship capacity (TEU)		
	4000	**18000**	**18000**
Loading/Unloading rate (TEU/h)	92/94	92/94	215/215
Operating speed (kts)	20/15	20/15	20/15
Cost component (%)			
Inventory	38/49	85/88	83/86
Handling	12/14	8/8	9/9
Transport	50/37	7/4	8/5\

of the chain's cost when only the inventory cost during loading and unloading of containers (TEUs) at the hub ports is taken into account.

Table 3
Structure of the total cost of given supply chain: - The inventory cost
During <u>loading + unloading</u> containers (TEUs) included

Operating characteristics	Container ship capacity (TEU)		
	4000	**18000**	**18000**
Loading/Unloading rate (TEU/h)	92/94	92/94	215/215
Operating speed (kts)	20/15	20/15	20/15
Cost component (%)			
Inventory	24/36	69/75	56/64
Handling	14/18	16/17	24/23
Transport	62/46	15/8	20/13

As can be seen, by excluding the inventory cost during collecting and distributing of containers (TEUs) at both ports, the share of this cost substantively decreases and the share of transport cost increases independently on the class of ship fleet serving the chain. However, the share of the former (inventory) cost remains much higher and the share of the latter (transport) cost remains much lower in case when the chain is served by the fleet of mega ships than in case when it is served by its smaller counterpart. In this case, reducing of the ships' operating speed also contributes to increasing of the share of inventory cost in the total chain's cost.

4. Conclusion

This paper has developed the analytical model for estimating the economic performances of supply chain(s) served by different classes of the freight transport vehicles including the mega ones. The model has been applied to the case of the intercontinental supply chain served by the liner shipping according to the specified scenarios of exclusively using: i) nominal container ships (i.e., the Panamax class of the capacity of 4000TEU (Twenty Foot Equivalent Units)), and ii) the mega container ships (i.e., the Triple E Class of the capacity of 18000TEU). The results from application of the model have shown the following effects of using the fleet of mega container ships on the chain's performances in the given case:

- Significantly lower transport (operational) cost of mega ship(s); and
- Substantively higher the average total cost of the chain served by mega ships due to dominance of the inventory cost, which otherwise can be reduced by speeding up collecting, loading, unloading, and distributing (i.e., handling) of goods/freight shipments (containers - TEUs) at the chain's hubs (This (inventory) cost tends to increase by reducing the ship operating speed of either class due to extending transport time).

These results clearly indicate that the liner shipping companies deploying mega ships should be prepared to pass a part of their benefits (profits) gained thanks to the much lower transport costs to the shippers and receivers in order to compensate their much higher inventory and handling costs of goods/freight shipments. Similar happens at the supply chains served by the mega vehicles operated by other transport modes – road, rail, and air, thus making effects/impacts of the mega vehicles on the economic performances of supply chain(s) they serve generous. .

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