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Do freight transport time savings translate to benefit for transport consuming companies?

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Abstract

It is common practice in Benefit - Cost analysis to consider freight transport time savings (FTTS) as a benefit for both transport producing and consuming companies. While transportation projects and policies resulting in FTTS are expected to have a positive effect on carriers' performance reducing time related transport costs and improving service, this is not always the case for the demand side of the transport market. Using System Dynamics in order to model the internal supply chain of a transport using company and simulate several scenarios, we argue that FTTS do not necessarily translate to benefit for shippers, but their effect depends strongly on the structure of the company's decision making process.

Keywords: Freight transport time, benefit – cost analysis, Systems Dynamics

1 INTRODUCTION

According to the latest EU's Guide to Cost-Benefit Analysis of Investment Projects travel time saving is one of the most significant benefits that can arise from the construction of new, or improvement of, existing transport infrastructure (EU, 2015). FTTS are expected to have a positive effect on carriers' performance reducing time related transport costs such as driver wage costs and vehicle operating costs per trip as well as improving service, especially reliability, facilitating the timely delivery of transported goods. However, the mechanisms that link FTTS to supply chain benefits and business performance are much more complex (US DOT, 2006, Sambracos and Ramfou, 2013, 2014).

Traditional Cost-Benefit analysis does not fully account for the benefits of transport improvements that accrue to shippers from cost savings and service improvements since it mostly considers first order benefits (US DOT FHWA, 2004). Several studies exist that try to fully quantify the benefit that freight transport companies can realize from FTTS, however there is no consensus nor on the magnitude of this effect not on the methods used to elicit it demand (Feo-Valero et al. 2011).

In this paper Systems Dynamics modeling and simulation is used in order to explore the mechanisms that translate FTTS to benefits for transport consuming companies. After a review of prior research in the field, a generic model is built and several scenarios are developed in order to measure the value of FTTS.

2 PRIOR RESEARCH

The value of freight transport time savings (VFTTS) is the benefit that derives from a unit reduction in the amount of time necessary to move a shipment from an origin to a specific destination. Demand for freight transport is a derived one, resulting from the spatial interaction between complex business processes. Therefore, in order to understand the value of savings in freight transport time, it is necessary to consider the wider context of logistics, production and trade activities, through which time acts as a resource (Tavasszy and Bruzelius, 2005).

Traditional CBA focuses on first order benefits from FTTS that include reduced vehicle operating times and reduced costs through optimal routing and fleet configuration for the carriers. Transit times may affect shipper costs also such as for spoilage and also scheduling costs. In the short run, demand for transportation is rather inelastic since nothing changes for the shippers except for the cost of freight movement, since they continue to ship the same volume of goods the same distance between the same points (US DOT FHWA, 2001).

Longer term reorganization gains due to FTTS refer to adjustments that transport consumers (shippers and consignees) make in their logistical arrangements in response to lower costs of freight movement. Tavasszy (2008) classified firm's responses to FTTS into three categories that include transport, inventory and production reorganization. The first, involves changes in routes, type of vehicle used, modes of transport. Time influences the amount of inventory in transit and the value of the finished good. The second, involves the number, location and volume of inventories with time determining which clients can be served by which warehouse within service level targets. Finally, production reorganization involves a shift between materials used, changes in production location or basic production technology changes. It is evident that FTTS benefits have a dynamic character since they evolve over time and do not strictly coincide with the time of the transport project. Producing a time table of benefits realization could only be indicative since the time that elapses between the FTTS, the reaction of the firms to it and the materialization of the benefit (or loss) varies. Such benefits are very difficult to be monetized and used in CBA but are expected to be 15% above direct user benefits (US DOT, 2004).

Reorganization effects are firm specific according to Boston Logistics Group who provided rough "first-cut" estimates (based on surveys on firms) of such benefits from a 10% transportation improvement for six unique Supply Chain Types (extraction; process manufacturing; discrete manufacturing; design-to-order manufacturing; distribution and reselling). The above types are differentiated by four variables: their production strategy (flow/continuous vs. batch/cellular); the transportation mode (ship/railcar, truckload/intermodal, or LTL/small package/air); the order trigger (make to plan, make to stock, assemble to order, make to order, or engineer to order); and the breadth of coverage between the raw material supplier and the end consumer (US DOT, 2006).

According to current bibliography, the quantification of the values of FFTS can be approached in two ways: by means of the factor cost approach or by modelling demand (Feo-Valero et al. 2011).

The factor cost approach estimates the value of FTTS on the basis of the decrease in cost that a reduction in FTT entails for a transport using company. Shippers estimate all costs that can be reduced due to a decrease in transportation time Such costs are vehicle costs dependent on time (fuel, maintenance, tires, vehicle taxes and insurance, depreciation), drivers and maintenance workers' wages, necessary overheads (such as training and social security payments) and in some cases the depreciation of goods while in transit (Odgaard et al. (2005). However, costs that are not directly related to the transport itself, such as logistics or inventory costs are not considered in this approach, therefore ignoring cost trade-offs that will ultimately affect the magnitude of the benefit.

Behavioral models on the other hand are used mainly for modelling passenger transport demand and consider the decision maker as a consumer of transport services. The decision maker in charge of the shipment faces a utility maximization problem, taking into consideration parameters such as the cost and quality of the service for each mode and the uncertainty associated to choosing that mode. In such models, the VFTTS constitutes the marginal rate of substitution between transport time and transport cost and is given by the estimated coefficient for time divided by the cost coefficient (Feo-Valero et al. 2011).

Inventory models are behavioral models that incorporate variables related to production, such as shipment size and frequency of shipment, aiming at maximizing a profit function of the transport consumer. Baumol and Vinod (1970) were the first to introduce the inventory theoretic approach that considers the trade-off between inventory and transportation in an effort to minimize total logistics cost, while maintaining the necessary level of customer service and considering demand and lead time uncertainty. In this framework the value of time for the shippers has two components: the reduction of inventory costs occurring during transportation and the reduction of the costs of holding inventories to respond to unexpected change in the demand.

Data for disaggregated models can be obtained by means of revealed preference or stated preference experiments (EU, 2015). In both cases, the final objective of the researcher is to discover how the interviewee – shipper of consignee - values transport attributes. Several authors have provided a review of studies on the valuation of freight transport time. Feo-Valero et al. (2011) has confirmed the dominance of SP surveys and behavioral models and have showed a remarkable variation in the values that transport users put on FTTS. Such differences were explained partly by the different methods adopted to collect observations and partly by the influence exerted by contextual factors such as the trip distance, the country where the study is developed, the per-capita GDP, the category of transported goods and the transport unit used.

Revealed Preference surveys face practical limitations basically associated with the high survey costs, the difficulties in collecting responses for new transport services, the ambiguity of the choice set (Ortúzar and Willumsen, 2011). Stated Preference data share the problem of "hypothetical bias" that is the deviation from real market evidence (Hensher, 2010). This may happen due to the dependence of the results on the capability of the researcher to conduct the survey and also the possibility that the answer may not reflect the behavior that the respondent would adopt in a real situation. Indeed, it is difficult to identity the decision-maker or makers in a firm. While existing approaches assume that there is a unitary decision-making process just like in passenger surveys, when it comes to companies there are diverse actors involved in the transport process coming from the procurement, production, inventory, marketing or distribution department of the firm. They do not have control or knowledge of all decisions made throughout the firm's supply chain, especially when it comes to future decisions. Therefore, the results of these methods are ambiguous since the same information if interpreted and processed by a different decision rule will yield different decisions and therefore results.

3 RESEARCH METHODOLOGY

3.1 Systems Dynamics

Dynamic complexity makes it difficult to assert the effect of FTTS on transport demanding companies. System Dynamics is a computer-aided approach for analysing and solving complex problems with a focus on policy analysis and design. Initially introduced as Industrial Dynamics, the field developed from the work of Jay W. Forrester at the Massachusetts Institute of Technology (Forrester 1958, 1961). Industrial Dynamics was defined as the study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decision and actions) interact to influence the success of the enterprise.

Systems are modelled using flow rates and accumulations linked by information feedback, forming loops and involving delays and non-linear relationships. Computer simulation is then used in order to infer the time evolutionary dynamics endogenously created by such system structures. The purpose is twofold: firstly to learn about their modes of behaviour and secondly to design policies that improve performance. The essential viewpoint taken by System Dynamics is that feedback and delay cause the behaviour of systems, i.e. that dynamic behaviour is a consequence of system structure (Morecroft, 2015).

3.2 Developing the model

Freight transportation facilitates the processes of the procurement, the production and the delivery of goods to their destination since it allows for the inbound transportation of production materials from the supplier and the outbound transportation of finished goods to the customer. Freight transportation performs an intermediary role in the internal and external supply chain providing the bridging function between supply and demand for goods (Coyle et. al. 2010).

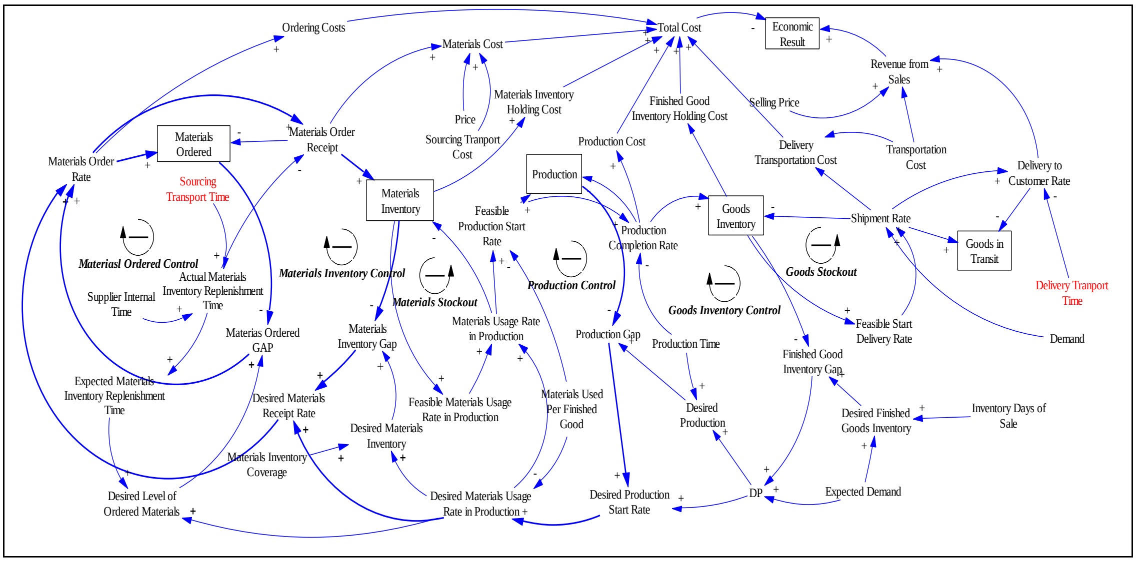
In this generic model a transport using company is considered that is part of a traditional supply chain. Inventories are set according to demand information flowing upstream from the next tier of the supply chain. For simplicity reasons we assume that the company follows a make to stock strategy and tries to fulfill demand from current finished good inventory.

In Figure 1 the structure diagram of a typical transport using company is illustrated based on Sterman (2000) and Morecroft (2015) depicting its internal supply chain. It consists of the stock (represented by rectangles and act as accumulations) and flow structure of the system (represented by arrows pointing into and out of the stock) for the ordering, receipt, storage of materials, production and storage of finished goods and finally their delivery to customers. Also, it includes the decision structure governing the flows that include policies for ordering production materials, scheduling production, fulfilling orders from production and customer satisfaction.

In this generic model, decisions of all actors are considered. The company receives orders from customers and then adjusts production in order to meet demand. Procurement managers order materials from suppliers in order to maintain materials inventories sufficient for production to proceed at the desired date. Apart for variations in demand they must adjust for delivery delays and possible restrictions in order quantity. The producer maintains a stock of Ordered Materials to the supplier, Materials Inventory, Work in Process Inventory, Finished Goods Inventory and Goods in Transit indicating goods transported to the customer. Inflows to these stocks add to them while outflows subtract from them, while both are subject to several decision rules. Finally, economic result of all logistics activities is calculated as the difference between money inflows and outflows.

There are six negative feedback loops in the model forming the basis of systems perspective where the typical thinking style is circular starting from a problem expressed as a discrepancy between a goal and the current situation, moving to a solution and then back to the problem. Problems do not just appear but rather spring from other decisions and actions that may have obvious or even hidden side effects (Morecroft, 2015). The Materials Ordered Control loop adjusts Materials Order Rate in order to move the level of the Materials Ordered to the desired level. Accordingly, the Materials Inventory Control loop, the Production Control and Goods Inventory Control loops whose aim is to adjust Materials Inventory Level, Production and Goods Inventory to their desired levels. The Stockout loop of Materials and Goods regulates shipments of materials to production and of finished goods to customers in order for the company to run production and satisfy demand respectively.

Figure 1: Analytical model structure



3.3 Model assumptions and parameters setting

Several assumptions were made regarding the company's inventory policy, production scheduling, transportation and other operational details, as well as the finished goods' demand. Some of them are rather conservative but they apply in an effort to simplify the model and discuss the effects stemming mainly from changes in freight transportation time and not in other variables. Demand for the company's goods is considered to be exogenous and normally distributed.

With regard to the inventory control policy, the model assumes a continuous review inventory system where the Desired Goods Inventory and the Desired Materials Inventory depend on the expected demand for goods from customers and materials from production and the days of coverage the company desires to have, according to the following formulas:

Desired Goods Inventory = Expected Demand x Inventory Days of Sales (1)

Desired Materials Inventory = Desired Materials Usage Rate
+ Materials Inventory Coverage (2)

The order quantity (Materials Order Rate) placed with the upstream supplier is based on the Materials Ordered Gap (difference between the Actual Materials Ordered and Desired Materials Ordered), the Materials Inventory Gap (gap between Actual Materials Inventory and Desired Materials Inventory), the Production Gap (gap between Actual and Desired Production), the Goods Inventory Gap (gap between Goods Inventory and Desired Goods Inventory as well as on any restrictions that exist in the materials order quantity. In the model it is assumed that there are no restrictions to the order quantity the company can order from suppliers.

Freight transportation time affects the Materials Inventory Replenishment Time that is the total time that elapses between placing an order to the supplier and receiving it. This time typically consists of the time to transmit the order, the time for the supplier to process the order and have the ordered goods ready for dispatch (considered as exogenous, since the manufacturer cannot affect it), the time to transport the ordered goods and the time required to unload and store goods in the company's warehouse (considered to be minimum due to modern storage technology). For simplicity reasons it is assumed that the Actual Materials Inventory Replenishment Time is the sum of the Supplier Time and the Sourcing Transportation Time.

For the Business as Usual (BAU) scenario it is assumed that the Actual Materials Inventory Replenishment Time is known to the company at all stages of simulation, and is used as an input in order to estimate the Desired Materials Ordered to the supplier based on the thinking that the company wants incoming orders and material inventory in order to run production during the lead time between placing and receiving the order. Therefore:

Desired Materials Ordered = Desired Materials Usage Rate in Production
x Expected Materials Inventory Replenishment Time (4)

Desired Materials Usage Rate in production is a function of the Desired Production Start Rate and the Materials required to produce a good. Therefore:

Desired Materials Usage Rate = Desired Production Start Rate
x Materials per Product (5)

Accordingly, transportation time affects the Delivery Time to customer along with other order processing times that are considered to be minimum. It is assumed that goods are transported to the customer on demand without order batching so each time the company receives an order it is immediately served providing there is adequate inventory. Every time a shipment commences (Shipment Rate to Customer – DRC) the stock Goods in Transit (GIT) increases until goods are delivered to the customer (Delivery Rate to Customer - DRC). Therefore are:

$$GIT_t = \int_{t_0}^{t} (\mathrm{SRC} - \mathrm{DRC})\,ds + GIT_{t_0} \quad (6)$$

With regard to measuring the value of FTTS the stock Economic Result is used that is increased by cash inflows stemming from Revenues from Sales and decrease by cash outflows stemming from Total Cost. Total Cost is the sum of Materials Order Cost, Materials Acquisition Cost, Materials inventory Holding Cost, Goods Inventory Holding Cost, Production Cost and Delivery Transportation

Cost. Materials Ordering Cost is the fixed cost per order irrespectively of the order quantity, Materials Acquisition Cost is the cost of the ordered materials plus the transportation cost, Materials Inventory Holding Cost and Finished Goods Inventory Holding Cost is the cost for holding one item in stock, Production Cost is the cost of production and Delivery Transportation Cost is the cost for transporting goofs to the customer.

The benefit of freight transport time savings (VFTTS) is the profit (or the loss) that the company will enjoy after a reduction in the materials sourcing or the goods delivery transportation time.

3.4 Scenario building and simulation results

The specific parameter settings used in this model, including the initial settings for all stock are included in Table 1. Initial values were estimated so as to ensure that the model starts with zero gaps between the actual and the desired states of the system. Unconstrained warehouse, production and transportation capacity is assumed in order to simplify the model, making it easier to interpret the results that are the result of FFTS and not confounded by constrained capacity.

Table 1. Parameter settings of the model (BAU scenario)

Actual Demand (AD)	Normally distributed, Mean = 20products/day, SD = 5 products /day, maximum number of orders= 30 products /day and minimum number of orders= 0 products /day.
Expected Demand (ED)	20 products/day
Supplier Time (ST)	2days
Sourcing Transportation Time (STT)	8days
Delivery Transportation Time (DTT)	3days
Production Time (PT)	2days
Materials Order Cost (MOC)	3€/order
Materials Purchase Price (MP) exl. transportation cost	8€/material
Selling Price (SP) exl. transportation cost	100 €/product
Sourcing Transportation Cost (STC)	2€/material
Materials Inventory Holding Cost (MIHC)	10 €/material/year or 10/365 x MI €/day
Finished Goods Inventory Holding Cost (FGIGCC)	20 €/product/year or 20/365 x FGI €/day
Production Cost (PC)	10 €/product
Product Delivery Transportation Cost (DCT)	5€/product
Materials Inventory Coverage (MIC)	5 days
Inventory Days of Sales (IDS)	3 days
Materials Per Product (MPP)	5 materials/product
Materials Supply Line (MSL)	Initial Value = 1000
Materials Inventory (MI)	Initial Value = 500
Work in Process (WIP)	Initial Value = 40
Finished Goods Inventory (FGI)	Initial Value = 60
Goods in Transit	Initial Value = 20

The model was simulated for 1000 days and results were produced on a daily basis (time step = 1day) using Vensim Ple software. For the BAU scenario, all parameters including transportation times are kept constant and the Economic Result (Inflows – Outflows) is estimated. Changes in transportation time can occur at two points affecting the Sourcing Transportation Time or/and the Delivery Transport Time. Changes were introduced at specific time spots and several scenarios were built based on different assumptions regarding the reorganization decisions that the company could take as a reaction to FTTS (Table 2).

Table 2. Scenarios of FTTC and company reaction

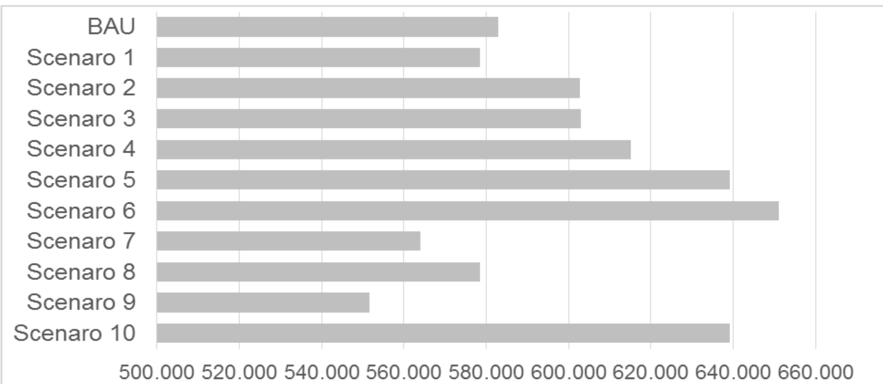
Scenario	Sourcing Transportation Time - STT (days)	Delivery Transportation Time – DTT (days)	Materials Inventory Coverage	Goods Inventory Coverage	Company Reaction
BAU	8	2	5	3	-
1	6 (at t=100)	2	5	3	No
2	6 (at t=100)	2	5	3	EMIRT=8days at t=110)
3	6 (at t=100)	2	5	3	EMIRT= 8days at 105)
4	6 (at t=100)	2	4 at 110	3	EMIRT=8days at t=105)
5	6 (at t=100)	2	2 at 110	3	EMIRT=8days at t=105)
6	6 (at t=100)	2	1 at 110	3	EMIRT=8days at t=105)
7	6 (at t=100)	2	1 at 110	2	EMIRT=8days at t=105)
8	6 (at t=100)	1 (at t=200)	5	3	No
9	6 (at t=100)	1 (at t=200)	2 at 110	2 at 110	EMIRT=8days at t=105)
10	6 (at t=100)	1 (at t=200)	2 at 110	3	EMIRT=8days at t=105)

4. ANALYSIS

Simulations of scenarios 1-10 highlight some very important conclusions regarding the economic effect of changes in transportation time that are presented in Figures 2 and 3. It is evident that in Scenario 6 the company has the highest economic result. In this scenario, the company reacts almost immediately after the FTTS and adjust the expected materials inventory replenishment time according to the saving in the sourcing transportation time and also the materials inventory coverage. The second best solution is Scenario 10 where the company faces a reduction in inbound and outbound transportation time, adjusts the expected materials inventory replenishment time and the materials inventory coverage.

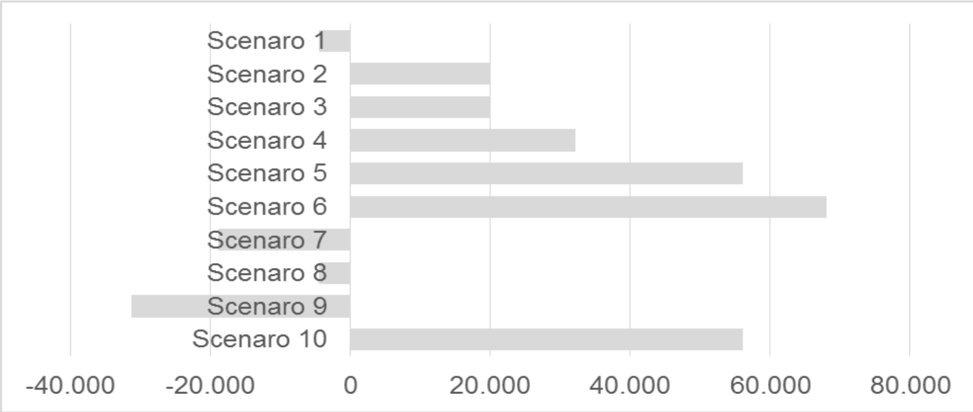
The worst scenarios were scenarios 1, 7 and 9 for different reasons. In Scenario 1 the company does not change its materials ordering policy, since it does not consider the FTTS when deciding the materials order quantity. In the other 2 scenarios, although the company adjusts its ordering policy, it decides to reduce the finished goods inventory coverage, resulting in goods stock out and therefore reduced sales and revenues. The effect of a reduction in Delivery Transport Time is more straightforward to trace since it affects the Delivery to Customer Rate and consequently the Revenues from Sales since customers pay for their ordered goods upon their receipt. A realistic extension of the model would be to assume delivery sensitive customers and link customer delivery time to Actual Demand. In this case the later variable will be considered to be endogenous and a function of delivery time, assuming that customer satisfaction and ultimately demand depends of Delivery Transport Time. However, it is difficult to fully map the link between the delivery transportation time and customer satisfaction.

Figure 2: Economic Result for all scenarios (estimation in €)



Knowing the economic effect of every scenario it is easy to understand the value of freight transport time savings, that is calculated as the difference between the economic result for the Business as Usual scenario and each scenario. The VFTTS is reported in Figure 3 and shows that in Scenario 6, the reduction in FTTS has the biggest profit for the company, while in Scenario 9 the FTTS led to a loss.

Figure 3: The value of FTTS for all scenarios (estimation in €)



5. CONCLUSIONS

After modeling the internal supply chain of a generic company, it is evident that the answer to the question that this paper sets in its title is negative. Savings in freight transportation time do not always result to benefits for the company. The main reason behind that is that he behavior of a system cannot be known just by knowing the elements of which the system is made of (Meadows, 2008).

The effect that FTTS will have on the economic result of companies depends strongly on the decision rules they apply with regard to the ordering and the inventory policy and the time horizon of their reorganization. Different parameters and values are expected to alter the results and lead to different FTTS values. The above are in line with the existing theory indicating that the reactions of companies to FTTS may include reorganization of the ordering, inventory and production policy.

A second conclusion deriving from the above is that current methods used to elicit the value of FTTS may not safely measure this effect due to several impediments such as the existence of dynamic complexity due to the time delays between taking a decision and its effects, the dynamicity and nonlinearity of systems, the limited information of decision makers, the poor scientific reasoning skills, the private agendas of decision makers leading to game playing and misperceptions of feedback (Sterman, 2000). Al the above hinder peoples' ability to understand the structure and dynamics of complex systems and therefore project their reaction to changes such as the ones in freight transportation time. Simulation models provide the possibility to include estimations of difficult to measure factors allowing the inclusion of all important parameters based on real world data or on estimates from actors within firms.

The use of Systems Dynamics revealed several advantages compared to the traditional SP technics. Time profiles for all variables used are returned, from the initial time until the end of the time horizon allowing for comparisons between the BAU - and all possible scenarios. Also, the gradual introduction of freight transport time changes is allowed along with the adaption of decision rules and operating conditions of the firm. Moreover, simulation allows the tracing of all variables’ values and causes behind the results on a step by step basis.

Several assumptions have been made in this article regarding the transportation, inventory and production capacity as well as the examination of more business strategies like for example the negotiation of minimum order quantities with the supplier, the introduction of discounts depending on the ordering quantity, the development of a link between delivery time and customer demand. Such inclusions in future research would make the model more complex and also more realistic.

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