USING SYSTEM DYNAMICS TO EVALUATE LOGISTIC PERFORMANCE

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Abstract
Starting from the first industrial applications in the Sixties, the importance of logistics has grown over time following the changes in market requirements and the technological and organisational transformations carried out by companies. In order to gain competitive advantage in today's dynamic global marketplace a proper management of logistic resources is required and for this purpose it is essential that suitable performance measures are monitored.
Since organisations are now starting to view themselves no more as stand-alone businesses, but as links in a supply chain, an important issue is analysing how performance spreads throughout this chain, from raw material suppliers as far as end customers. Moreover, for a complete evaluation of logistic service both operational and economic/financial indicators should be used. These last, however, descend from technical metrics, since every operational element causes an expense. Thus, in order that a company might balance costs and quality, economic and financial measures should be univocally referred to operational ones, so that each supply chain activity has a correspondence with an economic/financial item.
In the paper a model for the evaluation of logistic performance within a company is presented. With the aim of transforming it in a supply chain oriented framework, the tool of System Dynamics (SD) is explored and a case study is described. The application of SD to connect operational and economic/financial measures is also proposed.
The present paper falls within the authors' research project about supply chain performance measurement with the use of System Dynamics.

1. Introduction

Since its first industrial applications in the Sixties, the concept of logistics has evolved over time. After focusing on operational activities and their related costs in the Seventies and on the integration of the *Internal Supply Chain* in the Eighties, from the Nineties, with the growing recognition that whole supply chains, and no longer single companies, are competing (Cokins, 1999; Christopher, 2000; Lambert, 2001), logistics has turned its attention to the integration of the *External Supply Chain*, including suppliers and customers (Dallari, 2005). Nowadays logistics has a strong impact on strategy since it takes part in very important decisions concerning not only products, but also purchasing, manufacturing and distribution networks. Logistic competence is becoming a critical factor in creating and mantaining competitive advantage (Bowersox and Closs, 1996) but, in order to be able to discover why they gain or loss competitiveness, companies need to properly measure logistic performance.
The importance of measurement for decision – making in logistics has been emphasized since the Eighties, as the Just in Time revolution asserted that information, and not a high level of stock, is required to assure a timely and precise supplying (Fawcett and Cooper, 1998). Moreover, the main aim of Just in Time, reducing waste, leads manufacturing processes to purchase, produce and distribute only when necessary, thus underlying the need of evaluating logistic performance measures able to capture time. In these last few years, the ever increasing complexity of supply chains has also put pressure on the measurement of those activities required to coordinate and control integrated processes and channels. As a matter of fact, any process which is not monitored cannot be improved

(Artley and Stroh, 2001; Lohman, *et al.*, 2004): because its current and target values are not known, it is impossible to understand what should work better (Dallari, 2005). That is why without an organic and exhaustive set of measures a company is only able to assess its logistic performance *a posteriori*, often achieving unsatisfying results. Another reason for measuring performance is the fact that the combination of slower economic growth, increased global competition and possibility to gain access to the best resources available worldwide has forced firms in every industry to concentrate on efficient and effective deployment of logistic resources (Bowersox and Closs, 1996; Fawcett and Cooper, 1998). Finally, it is essential for a company to assess logistic service because this is an important driver of customer satisfaction. According to some authors, the true purpose of a logistic performance evaluation system should just be focusing on service quality all those people who interface with customers (Dallari, 2005).
The remainder of the paper is organized as follows. Section 2 briefly presents LOGISTIQUAL, a model for logistic performance evaluation at a single supply chain echelon. In section 3 the issue of measuring the performance of a whole supply chain is considered, together with the use of System Dynamics for this purpose. In section 4 the development of a System Dynamics model is detailed and a case study is described. Section 5 shows how System Dynamics can also help to tackle another very important subject in performance measurement: linking operational metrics to economic and financial ones. Finally, conclusions and issues for future research are presented in section 6.

2. A framework for logistic service quality evaluation: LOGISTIQUAL model

In the logistic industry, service quality can be considered as the measure of how well the logistic system is performing in creating time and place utility for a product (Neo, *et al.*, 2004). A way to measure logistic service quality is referring to SERVQUAL, also known as PZB model (Parasuraman, *et al.*, 1985, 1988), a widely used framework for service quality assessment. It has been demonstrated that there are five aspects common to the evaluation of every service and, thus, also the logistic one: Tangibles, Reliability, Responsiveness, Assurance and Empathy (Stank, *et al.*, 1999; Neo, *et al.*, 2004). This result was of fundamental importance to the development of LOGISTIQUAL model: on the basis of the analysis of real logistic processes a correspondence between the five dimensions of SERVQUAL and the activities involved in a logistic service was found. Particularly, considering a single process, that is to say a single company in a supply chain, and adapting PZB model to the specific issue, LOGISTIQUAL (Rafele, 2004; Grimaldi and Rafele, 2004, 2006) asserts that the logistic performance classification for a manufacturing supply chain could be identified by three macro – classes, each of them including some sub – classes (Figure 1).

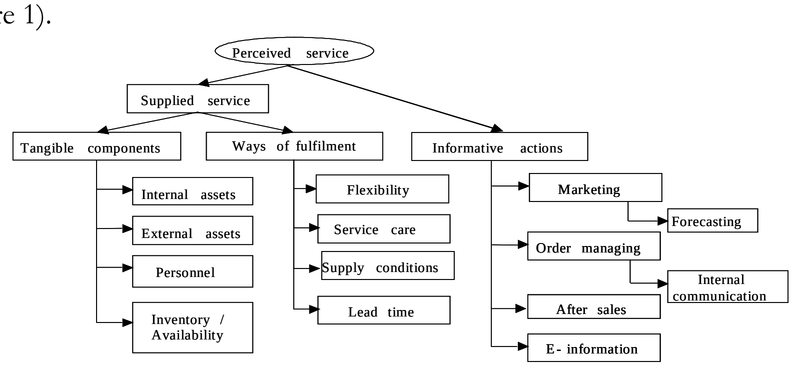

Figure 1 LOGISTIQUAL structure

Tangible components macro – class corresponds to SERVQUAL dimension Tangibles, whereas Way of fulfilment to Reliability and Responsiveness and Informative actions to Emphaty and Assurance. LOGISTIQUAL covers all the sides of logistic service, identifying the specific components (sub-classes and, for each of them, performance indicators) necessary to measure logistic performance. After having been extensively validated in both manufacturing and service settings (Grimaldi and Rafele, 2004, 2006), this model is now being expanded to evaluate the performance of whole supply chains.

3. Measuring overall supply chain performance

Recent literature about performance measurement highlights the necessity to evaluate the performance of supply chains as a whole and not only of their single echelons (Brewer and Speh, 2000; Gunasekaran, *et al.*, 2001, 2004; Bullinger, *et al.*, 2002).
According to Lambert and Pohlen (2001), several factors cause the current lack of supply chain oriented performance measures. Companies do usually not adopt a supply chain perspective and are not much willing to share information with their competitors. Moreover, it is difficult to develop metrics which evaluate the performance of more than one company. Lohman *et al.* (2004) state that among the difficulties companies experience in implementing a supply chain oriented measurement framework there are little cohesion between metrics evaluating different sub – processes, uncertainty on what to measure and dispersed IT infrastructures that do not support supply chain integration. Many companies are now starting to measure external performance, but they often consider only first tier suppliers (Caridi, *et al., 2002).* However, despite this situation, some authors attempted to define measurement frameworks aiming at evaluating overall supply chain performance. For example, Brewer and Speh (2000) and Bullinger (2002) adapt the Balanced Scorecard for this purpose and present possible supply chain oriented indicators.

3.1 The evolution of LOGISTIQUAL towards supply chain performance

In order to expand LOGISTIQUAL model beyond the boundaries of single organisations, it has been considered that its definition allows it to be used to evaluate both the performance of a company, as it is perceived by its customers, and the performance of this company's suppliers. In this way, two frameworks have been derived (Grimaldi and Rafele, 2004, 2006).
The first, named Self – LOGISTIQUAL, aims at assessing outputs and internal processes. With this perspective, a company applies the model to evaluate the influence of its tangible means, executive procedures and informative actions on logistic service carried out for downstream customers. The second, named Source – LOGISTIQUAL, intends to assess inputs. In this case, a company applies the model as a customer of upstream suppliers, evaluating their tangible means, executive procedures and informative actions.
With the two perspectives LOGISTIQUAL can now evaluate suppliers' performance (Source – LOGISTIQUAL) and internal or toward customers one (Self – LOGISTIQUAL). Nevertheless, to determine quantitatively the relationships between these dimensions, a tool able to understand the mutual influences among indicators measured in different supply chain echelons is needed. The authors think that this tool could be System Dynamics.

3.2 Supply chain performance evaluation by means of System Dynamics

System Dynamics (SD) is the application of feedback control systems principles and techniques to managerial, organisational and socioeconomic problems. It focuses on the

behaviour of complex systems, representing them by means of stocks, flows and interacting feedback loops. In particular, SD views the behaviour of an organisation as the result of its structure, characterised by sources of amplification, oscillation and time delay and by information feedbacks (Roberts, 1999; Sterman, 2000).
SD can be a suitable tool to analyse supply chains (Sterman, 2000; Panov and Shiryaev, 2003; Schieritz and Größler, 2003). As a matter of fact, from a logistic point of view the behaviour of each company in a supply chain can be represented with a set of stocks, such as inventory, materials on order or finished products on order, linked by information and material flows. Moreover, amplifications, oscillations and time delays are pervasive in a supply chain (Akkermans and Vos, 2003). Decision rules often create important feedbacks among partners: these are primarly negative feedbacks that, with time delays, create oscillations. The amplitude of these fluctuations usually increases as they propagate from customer to supplier, originating an effect amplification along the chain called by Forrester *bullwhip effect* (Forrester, 1961).
According to *system thinking*, the philosophy on which SD is grounded, a supply chain should be analysed considering the entire set of consecutive sub-systems, connected bilaterally through the exchange of orders and goods, and not concentrating on each constituent organisation separately. This is more true when trying to understand the influences among performance metrics evaluated at different supply chain echelons: in this case it is necessary to go beyond the boundaries of single companies and undertake a global system analysis. An important issue in doing this is deciding where to put the boundary of the system and, consequently, of its SD model. Models must exclude all factors not relevant to the problem to ensure the project scope is feasible and the results timely (Sterman, 2000), but, at the same time, the wider a model is, the more cause and effect relationships and loops it will capture and the more precise the outcomes will be. Therefore, a balance has to be struck in order both to focus the analysis and to reach a satisfactory level of precision.
The authors believe that SD is a powerful tool to improve the effectiveness of LOGISTIQUAL model (Rafele and Cagliano, 2006). In fact, this framework gives a classification of indicators, but it does not link them. On the contrary, SD can help to define the relationships among performance metrics, both within a single company and in different companies, that a static model like LOGISTIQUAL is not able to capture.
In the next section, the guidelines for the development of a SD model to connect performance evaluated by LOGISTIQUAL at different supply chain echelons are given, whereas a case study shows the relationships among some logistic indicators referable to this measurement framework.

4. Developing a System Dynamics model to link logistic performance in a supply chain

4.1 Main steps in the construction of the model

In order to be easy to handle, the present model aims at linking logistic performance in a supply chain considering not the entire functioning of the system, but only the most significant elements affecting the indicators under study. For this reason, the first step in constructing the model is sketching Causal Loop Diagrams (CLDs) for each company concerned showing the elements influencing a certain performance measure. CLDs are graphical tools which help to conceptualise causal relationships and feedback loops existing in the real system. It is important to underline that these diagrams are only hypotheses and

must be tested. As a matter of fact, formalization and simulation often uncover flaws in CLDs and lead to improved understanding (Sterman, 2000). From CLDs, Stock and Flow Diagrams and the mathematical equations defining the model are derived. Performance indicators can be represented by auxiliary variables, which are neither stocks nor flows, and then they may be linked to stocks, flows or other auxiliary variables.
After formulating a SD model for each company, relationships between quantities belonging to different organisations are searched for, in order to connect all the sub-models. Afterwards, the overall model will be validated. Finally, simulation will quantify the links between various factors and metrics belonging to different supply chain echelons, making possible to explore how performance spreads from suppliers to customers. Since SD is a collaborative tool, the construction, validation and simulation of the model should result from the interaction between the modeler and people working in the analysed organisations. This is made easy by an extensive use of graphical languages.

4.2 A case study from the automotive sector

The aim of the present case study is showing the use of SD to link logistic perfomance of consecutive supply chain echelons through homogeneous indicators. CLDs and the most significant equations are detailed. It is important to notice that the influences among metrics discussed in this section will probably manifest themselves with some time delay. However, since it is difficult to evaluate delays from CLDs, the authors decided to postpone this kind of analysis until the development of a complete quantitative model.
The focus is on a medium - sized Italian company producing switches, sensors and electronic control units for some of the largest automotive manufacturers (Rafele and Cagliano, 2006). A representative product, a switch referred as S, is considered (figure 2).

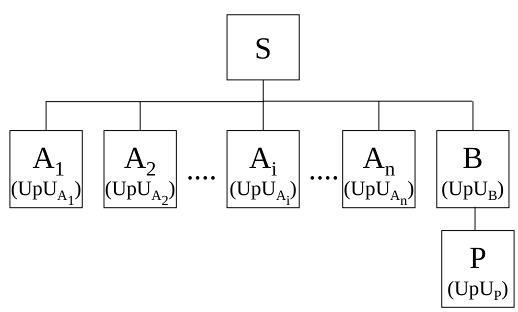

Figure 2: Bill of material of switch S

S is obtained by assembling components A_1, A_2, …, A_n, purchased respectively from the suppliers S_1, S_2,...,S_n, and component B, made from plastic material P by the internal moulding department. Let's S_P the supplier of material P. The "Usage" of each component or material j (j = 1…, n, B, P) "per Unit" of S (UpU_j) is also showed in figure 2. The focus company supplies S to customer C, in particular to its two plants C_1 and C_2. It is interesting to note that, even if belonging to a same company, C_1 and C_2 are considered as two different customers, with distinct customer codes.

The first step in the analysis is singling out the key performance indicators characterising the logistic service for the focus company. According to its management, *Input* and *Output Stock Turnover* (belonging to LOGISTIQUAL macro – class Tangible components) are very important metrics for this company because one of its main goals is to have low levels of stocks. Moreover, *Order Fulfilment Efficiency* (belonging to LOGISTIQUAL macro – class

Ways of fulfilment) is also crucial for a first equipment supplier. These indicators may be defined as follows.
Input Stock Turnover (IST_j) is calculated as the quantity of input j (component or material) used by the production process in a period over the average level of inventory for this input in the same period, or the level at the end of it.

$$IST_j = \frac{\text{Actual Input j Usage Rate} * \text{Time Bucket}}{\text{Input j Inventory}} \qquad (4.1)$$

In a similar way, *Ouput Stock Turnover* (OST_f) can be evaluated for every output f of a company (finished product) as follows, where t indicates each customer:

$$OST_f = \frac{\sum_t (\text{Ouput f Shipment Rate}_t * \text{Time Bucket})}{\text{Output f Inventory}} \qquad (4.2)$$

Let's notice that the output of a company is usually an input for its customers.

Order Fulfilment Efficiency (OFE_{ft}) is a measure of how a company is able to meet customers' requirements. It is evaluated for each output f and for each customer t and is defined as the ratio between the number of items fulfilled in a period and the total number of items potentially fulfillable during it.

$$OFE_{f\,t} = \frac{\text{Output f Shipment Rate}_t * \text{Time Bucket}}{\text{Quantity of Output f on Order}_t} \qquad (4.3)$$

In collaboration with the focus company's management and people working in the logistic department, all the most important factors influencing these metrics were identified, together with the relationships among them. Previous SD models about manufacturing settings were also reviewed (Sterman, 2000; Panov and Shiryaev, 2003; Schieritz and Gröβler, 2003). As the analysis of the focus company's business processes showed a strong assonance with Sterman's models (2000), these were chosen as a reference for the present work. Thus, the following Causal Loop Diagrams were sketched (figures 3,4,5,6,7,8). Since it has been observed that in the investigated automotive supply chain the dynamics of behaviour of all its companies are comparable, it can be supposed that they have similar structures of factors influencing the indicators under study. Therefore, definitions (4.1), (4.2) and (4.3) and the CLDs presented below will be assumed valid for both the focus company and its suppliers.

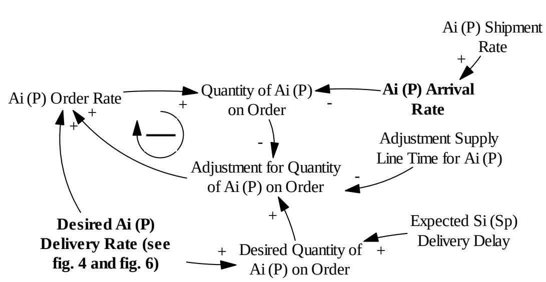

Figure 3: A_i ($\forall i$) and P order management

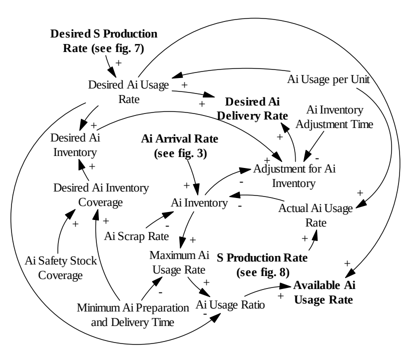

Figure 4: A_i inventory management ($\forall i$)

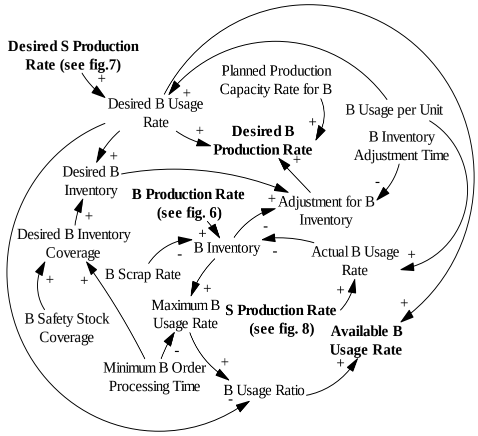

Figure 5: B inventory management

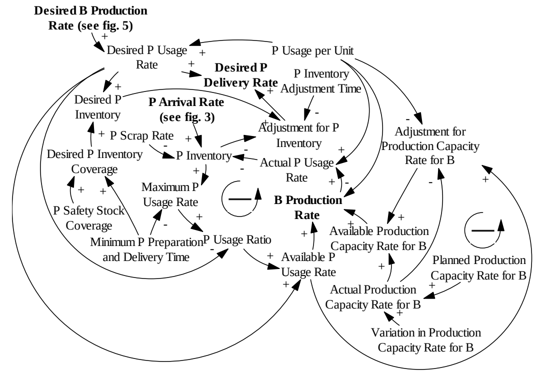

Figure 6: P inventory management

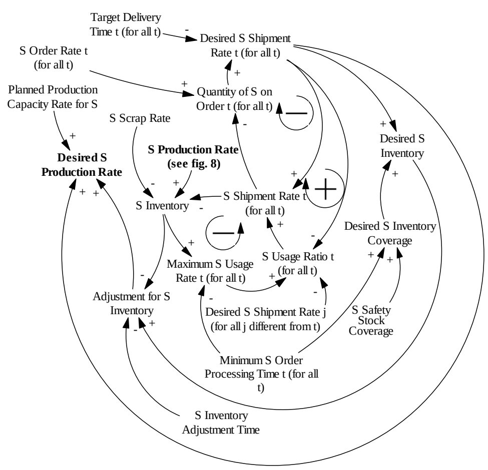

Figure 7: S inventory management (∀ customer t,j =1,2)

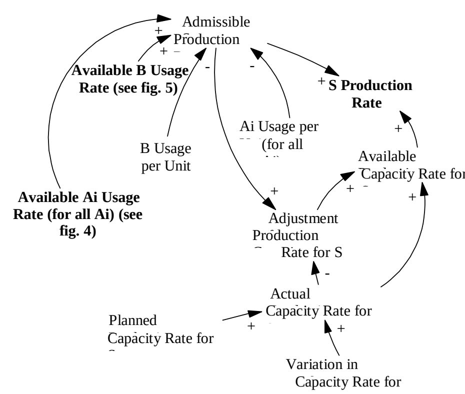

Figure 8: S production rate definition

Input and Output Stock Turnover. From figure 4 it can be stated that Actual A_i Usage Rate = S Production Rate * A_i Usage per Unit, ∀i. In the focus company S Production Rate is strictly related to the available quantity of material. As a matter of fact, if this allows to produce more than the actual production capacity (machine-hours and man-hours) does, the latter will be integrated, for example by means of overtime or multiskilled workers from other production departments. Thus, in figure 8 Adjustment for Production Capacity Rate for S = 0 if Actual Production Capacity Rate for S ≥ Admissible S Production Rate and Adjustment for Production Capacity Rate for S = Admissible S Production Rate – Actual Production Capacity Rate for S if Actual Production Capacity Rate for S < Admissible S Production Rate. An analogous reasoning is valid for B Production Rate (figure 6).
Therefore, for product S (figure 8):

S Production Rate = min (Admissible S Production Rate; Available Production Capacity Rate for S) = Admissible S Production Rate = f_k(Available k Usage Rate)

where k is the component, A_i (∀i) or B, with the smallest production potential. But Available k Usage Rate = g_k(u Shipment Rate), where u = A_i if k = A_i, ∀i, and u = P iff k = B (figure 3,4,5,6). Thus,

$$\text{S Production Rate} = f_k[g_k(\text{u Shipment Rate})] = g_k^{'}(\text{u Shipment Rate})$$

and Actual A_i Usage Rate = $g_k^{'}$(u Shipment Rate) * A_i Usage per Unit. The relationship between Actual A_i Usage Rate and u Shipment Rate allows to state that there is a link between IST_{Ai} (∀i) and OST_u measured by the supplier of u (see definitions (4.1) and (4.2)). Since Actual B Usage Rate = S Production Rate * B Usage per Unit (figure 5), this reasoning holds replacing A_i with B.
Within the focus company, there is a link between IST and OST. As a matter of fact, from figure 7 it follows that ∀t:

$$\text{S Shipment Rate}_t = \text{S Usage Ratio}_t * \text{Desired S Shipment Rate}_t$$

$$\text{S Usage Ratio}_t = l_t\left(\frac{\text{Maximum S Usage Rate}_t}{\text{Desired S Shipment Rate}_t}\right)$$

$$\text{Maximum S Usage Rate}_t = \frac{\text{S Inventory}}{\text{Minimum S Order Processing Time}_t}$$

$$\text{S Inventory} = \text{INTEGRAL}\begin{bmatrix}\text{S Production Rate} - \text{S Shipment Rate}_1 - \\ - \text{S Shipment Rate}_2 - \text{S Scrap Rate; S Inventory}_{t_0}\end{bmatrix}$$

Thus, ∀t:

$$\text{S Shipment Rate}_t = f_{1t}(\text{S Production Rate}) * \text{Desired S Shipment Rate}_t = f^{'}_{1t}(\text{S Production Rate}) \qquad (4.4)$$

but S Production Rate = (Actual A_1 Usage Rate/A_1 Usage per Unit) =…= (Actual A_n Usage Rate/A_n Usage per Unit) = (Actual B Usage Rate/B Usage per Unit) (figure 4 and 5) (4.5), so S Shipment Rate t, ∀t, and OST_S can be expressed as a function of either IST_{Ai} ∀i or of IST_B (see definitions (4.1) and (4.2)). Moreover, since Actual j Usage Rate = $g_k^{'}$(u Shipment Rate) * j Usage per Unit, ∀j = A_1,…,A_n,B, there is also a relationship between OST_S and OST_u measured by the supplier of u.
Finally, from figure 6,

$$\text{Actual P Usage Rate} = \text{B Production Rate} * \text{P Usage per Unit}$$

But, in a similar way as S,

$$\text{B Production Rate} = \min\left(\frac{\text{Available P Usage Rate}}{\text{P Usage per Unit}}; \text{Available Production Capacity Rate for B}\right) = \frac{\text{Available P Usage Rate}}{\text{P Usage per Unit}} = f_2(\text{P Shipment Rate})$$

because Available P Usage Rate is a function of P Arrival Rate (figure 6), which in turn is a function of P Shipment Rate (figure 3). Thus, Actual P Usage Rate = f_2(P Shipment Rate)* P Usage per Unit and, as obvious, there is also a link between IST_P and OST_P measured by S_P (definitions (4.1) and (4.2)).

Order Fulfilment Efficiency. It is possible to prove that OFE_{St},∀t, depends on the OFE measured by the supplier of component/material u. As explained above, S Shipment Rate$_t$ = $f_{1t}^{'}$(S Production Rate) and S Production Rate = $g_k^{'}$(u Shipment Rate), thus S Shipment Rate$_t$ = $f_{1t}^{'}[g_k^{'}$(u Shipment Rate)], ∀t. This relationship between S Shipment Rate$_t$

and u Shipment Rate allows to state that there is a link between OFE_{St}, $\forall t$, and OFE_u measured by the supplier of u with regard to the customer "focus company" (see definition (4.3)).
Moreover, from (4.1), (4.3), (4.4) and (4.5) it can also be stated that there is a relationship between OFE_{St},$\forall t$, and either IST_{Ai}, $\forall i$, or IST_B.

The authors are currently working with the focus company in order to refine, test and simulate with quantitative data the model presented in this paper. The approach based on SD is proving itself to provide a deep understanding of the focus company's logistic performance dashboard. As a matter of fact, the company was accustomed to evaluate the metrics belonging to it without considering their mutual influences. The tool of System Dynamics is giving a unitary vision of the dashboard, highlighting the relationships not only among internal performances, but also between them and those of the focus company's suppliers and customers.

5. Linking operational and economic/financial metrics

A proper supply chain management requires to take a broad view of the production and logistic system, measuring not only service factors, such as timeliness, availability and completeness, but also economic and financial elements. As a matter of fact, while day to day control of manufacturing and distribution operations is better handled with non financial measures, financial performance measurement is important for strategic decisions and external reporting (Gunasekaran, *et al.*, 2001). Many companies have realized the importance of adopting both financial and non financial metrics, but they often fail to understand them in a balanced framework. Thus, one main priority in actual research on supply chain performance evaluation is finding methods to link financial and non financial indicators (Grey, *et al.*, 2003; Neely, *et al.*, 2003). In literature, some approaches, mainly qualitative, have been proposed (Wouters, *et al.*, 1999; Ellram and Liu, 2002; Pohlen and Goldsby, 2003; Timme, 2003). Theoretically, a good tool for linking economic/financial metrics to operational ones is also Activity Based Costing (ABC). As a matter of fact, every economic/financial measure can be broken down into its cost elements and each of them may be linked to operational activities inside business processes by means of ABC. Connected to all these activities there will be indicators assessing how well they are performing: therefore, in this way there will be possible to understand the impact of a change in the value of an operational indicator on the related costs and economic/financial measures. In practice, however, this method can be applied only if the analysis is limited to specific aspects of business, such as, for istance, cost of transport, cost of order fulfillment or cost of warehousing. Its application to a quite general indicator like ROI leads to an unmanageable number of links between financial and non financial metrics.
Being able to clarify relationships among variables, System Dynamics may be a useful tool for the matter at issue. Economic and financial measures can be connected to operational quantities in CLDs and, through the link operational metrics – quantities in CLDs – economic/financial metrics, it will be possible to evaluate the impact of non financial indicators on financial ones. Two simple examples from the previous case study are given.

Sales over stock. It is a measure of the efficiency of sales and allows to compare the actual level of stock with that necessary to support a certain volume of sales. For finished product S it can be defined as follows (figure 9):

$$\frac{\text{Sales}}{\text{Stock}} = \frac{p * \sum_{t=1}^{t=2} (\text{S Shipment Rate}_t * \text{Time Bucket})}{c * \text{S Inventory}} \tag{5.1}$$

where c is the unit cost of goods sold, sum of cost of labour, cost of material, manufacturing costs, overheads and other direct costs, and p is the selling price, sum of unit cost of goods sold and unit gross margin (GM). Considering definitions (4.2) and (4.3) and substituting them into (5.1), it can be stated that Sales over Stock may be connected both to OST_S and to $OFE_{St}, \forall t$:

$$\frac{\text{Sales}}{\text{Stock}} = \left(1 + \frac{GM}{c}\right) * OST_S = \frac{p}{c} * \sum_{t=1}^{t=2} \left(OFE_{St} * \frac{\text{Quantity of S on Order}_t}{\text{S Inventory}} \right)$$

Cash turnover. This metric assesses the effectiveness of using cash resources to generate income. Even if its optimal value closely depends on the goals and policies of a company, it is desirable that it is as higher as possible. Cash turnover should be evaluated for all the products sold by a company, but here it will be calculated only for S, assuming that the focus company does not produce other products. It is defined as (figure 10):

$$\text{Cash Turnover} = \frac{\text{Sales}}{\text{Cash}} = \frac{p * \sum_{t=1}^{t=2} (\text{S Shipment Rate}_t * \text{Time Bucket})}{\text{Cash}} \tag{5.2}$$

Considering again definitions (4.2) and (4.3) and substituting them into (5.2), it can be stated that also Cash Turnover may be connected both to OST_S and to $OFE_{St}, \forall t$:

$$\text{Cash Turnover} = \frac{p}{\text{Cash}} * OST_S * \text{S Inventory} = \frac{p}{\text{Cash}} * \sum_{t=1}^{t=2} (OFE_{St} * \text{Quantity of S on Order}_t)$$

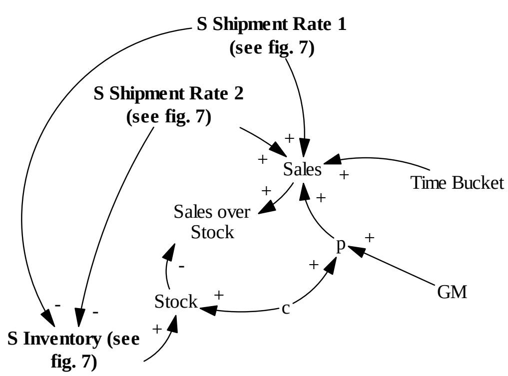

Figure 9: Sales over Stock definition

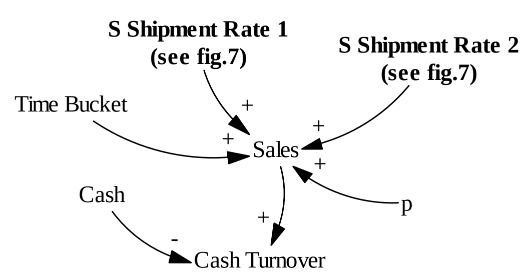

Figure 10: Cash Turnover definition

Management does often not completely know the links between operational and economic/financial aspects of an organisation. System Dynamics, requiring to determine the cause and effect relationships characterising the problem under consideration, forces to clarify the links already identified and to discover new ones. In this way, SD is a tool that helps to find those connections among various dimensions of performance which are essential to proper manage a company. As a matter of fact, different levels of logistic performance will for example give rise to different levels of capital tying up or to different costs. On the other hand, every company can afford certain costs and investments, depending on several factors such as its conditions or the general economic situation. In this case the relationships between operational and economic/financial performance will allow to determine the level of logistic service a company is able to deliver to its customers.

6. Conclusions and issues for future research

The increasing competitive pressure resulting from the globalization of manufacturing activities and markets induces organisations to measure the different facets of their performance and, among these, the logistic one. Till now, research has mostly focused on financial and/or non financial measures (first generation of performance measurement systems, Neely, *et al.*, 2003) and on the dynamics of value creation (second generation of performance measurement systems, Neely, *et al.*, 2003). Two are the main future challenges: evaluating the performance of entire supply chains and linking financial and non financial measures.

Starting from LOGISTIQUAL, a first generation performance measurement model, the paper tries to transform it into a supply chain oriented framework by using System Dynamics for connecting performance evaluated at two consecutive supply chain echelons. Moreover, it suggests the use of the scheme of analysis provided by System Dynamics as a basis to study the relationships between operational and economic/financial metrics.

Using an inductive approach, the authors are progressively expanding the model presented in this paper including in it multiple supply chain echelons. The final goal is succeeding in connecting the performance of all companies in a supply chain. With the purpose of making LOGISTIQUAL a complete measurement system, the authors are also working at the development of a systematic method to evaluate and analyse the impact of its operational metrics on economic and financial ones. They are currently defining a comprehensive classification of logistic costs in order to trace to it the activities underpinning operational indicators. The aim is to define a new measurement framework, similar to LOGISTIQUAL, but devoted to identify all the elements that contribute to determine logistic costs.

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