SUPPLY NETWORK DESIGN AND COLLABORATION: A PRELIMINARY STUDY

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Abstract
This paper is aimed at formalizing and testing a model for explaining the relations among supply chain design decisions (i.e. sourcing strategies, number of network stages, nodes' capacity and localization) and the need for collaboration between the nodes of pull-based supply chain. As a consequence, a causal diagram which depicts such relations is built and its validation is performed by means of simulation techniques and statistical analyses (ANOVA and linear regression). In particular, since the magnitude of the relations is out of the scope of the paper, the validation is done in relative terms. The results obtained by running the simulation model of the supply chain which represents the 'base case' are compared with the outputs of the models which simulates the original logistic network modified according to the above mentioned supply chain design elements. The statistical analyses allow the majority of the relations of the proposed causal diagram to be actually validated.

1. Introduction
Over the last years, the concept of production system has evolved to the one of supply chain, which has become a major research area. In this field, the majority of studies deals with supply chain management (Simchi-Levi *et al.* 2001), i.e. they basically suggest how to manage a logistic network once it has built up, so that planning methodologies, performances indexes etc. are assessed. The subject of supply chain design, i.e. of the partnerships definition and of the physical and logical structures required by a logistic network, has received a limited attention by academic researchers and industrial practitioners (Chopra and Meindl 2001). Beamon (1998) outlines that few scholars, when addressing the analysis of the determinants of supply chain performances (e.g. costs, inventory levels, responsiveness), take into account the variables related to supply chain design decisions - i.e. number of stages and the definition of which plant of the network will serve which customer - and any of them studies the two variables jointly. Supply chain design is basically composed of three main areas (Shapiro 2001): (i) supply chain composition, i.e. identification of entities (firms etc.) that should join the (constituent) logistic network; (ii) network structure, i.e. definition of the number of stages, of the sourcing strategies (multiple or single sourcing) of each entity and, finally, definition of the nodes' capacity and localization (Simchi-Levi *et al.* 2001); (iii) collaboration level among the nodes. With reference to the last area, it is worth to notice that some authors (Jagdev and Thoben 2001, Makatsoris and Chang 2004) consider the degree of collaboration among the nodes a supply chain design decision, whereas according to others (Simchi-Levi *et al.* 2001, Helbing and Lammer 2005) the degree of collaboration required is a result of the decisions taken in term of network structure.
This paper is focused on the supply chain design topic and, in particular, according to Simchi-Levi *et al.* (2001) and Helbing and Lammer (2005) is focused on investigating the relation among the topological features of a logistic network and the collaboration level needed among its nodes. The reason for this is almost threefold: (i) supply chain composition is an area where only early (even very interesting) proposals, based on simulation (Ding *et al.* 2005) and game theory (Cachon and Netessine 2003) have been done and it is an unknown area from the modern logistics approach (Cigolini *et al.* 2004); (ii) with reference to network structure, several algorithms and linear programming models to support decisions in such area have been developed (Sridhar *et al.* 1999, Chopra and Meindl 2001, Shapiro 2001) and the drawbacks they are characterized by have been already overcame (the majority

of these models are basically unable to consider both the time dynamics and the uncertainty, so that, to face uncertainty, some procedures focused on simulation or on stochastic programming have been drawn (Alonso-Ayuso *et al.* 2002, Santoso 2002)); (iii) finally, in the collaboration level research area, studies mainly concern with the analysis of why and how firms can collaborate (Jagdev and Thoben 2001, Kaipia *et al.* 2002, Smaros 2003, Makatsoris and Chang 2004), whereas the relevance of topological features for the dynamic behavior of supply chains (Helbing and Lammer 2005) and, as a consequence, for the degree of collaboration required among the supply chains' nodes, remains to be explored.

For the reasons above, the aim of this work lies in developing and validating a causal diagram, which expresses the impact of the logistic network structure on the need of collaboration. We measure the need of collaboration by calculating the number of stock outs, the number of entries in the stock out status and the quantity of stock out units (Simchi-Levi et al. 2001). Since the present work is focused on pull-based systems (see next section), the need for collaboration can be approximated by the stock-outs only and the stock level of the supply chain as a whole can be neglected. As a matter of fact, in a pull context the average stock level is *a priori* determined and it does not depend on the system dynamics (as a consequence, the need for collaboration generated by the supply chain design elements can not be figured out from such a variable). On the contrary, the current stock level strictly depends on the dynamic behavior of the system (which, in turn, depends, according to the hypothesis the present work refers to, on its topological features) but, since the current inventory allows the customers requirements to be satisfied or not, the dynamics of such a variable do not give any additional information on the need for collaboration than the stock-outs occurrence. (Chase *et al.* 1973).

The paper is arranged as follows: section 2 introduces the background, while sections 3 and 4 present the proposed model and its validation respectively. In section 5 some concluding remarks and suggestions for future researches are reported.

2. Background

It is widely recognized that collaboration represents a goal for supply chains: the lack of coordination results in several drawbacks, i.e. increase of manufacturing costs, inventory costs amplification, longer replenishment lead times, increase of transportation costs, growth of the labor-cost for shipping and receiving (Forrester 1961, Sterman 2000, Chopra and Meindl 2001).

In spite of the above mentioned drawbacks, the lack of collaboration is often experimented in real-life industrial environments due to either behavioral or information processing hurdles (Forrester 1961, Sterman 2000). Behavioral hurdles are: (i) the tendency of each supply chain node to consider its actions locally and to react to the current local situation rather than identify the root causes; (ii) the inability of each stage to learn from its actions, since the most relevant impacts (of the actions) occur elsewhere in the chain; (iii) the lack of trust among supply chain partners which causes opportunistic ways of doing at the expense of overall logistic network performance (Chopra and Meindl 2001). Information processing hurdles are: (i) forecasting based on orders by downstream nodes instead of on the final customer demand (ii) the lack of information sharing.

For this reason, several methodological patterns to achieve coordination in supply chains have been proposed in literature. These methods can be categorized according to the hurdles to collaboration they face; in particular, 3 schools of thought can be identified, i.e. (i) aligning goals and incentives, (ii) building strategic partnerships and trust; (iii) improving information accuracy. The first school of thought (Child and Faulkner 1998, Gulati and Singh 1998, Bowersox *et al.* 1999 and Brunell 1999) and the second one (Kumar 1996, Doz and Hamel 1998, Mariotti 1999, Liker and Choi 2004) are mainly focused on the lack of collaboration caused by conflicting objectives among the network nodes, i.e. the behavioral obstacles, whereas the third school of thought (Lee *et al.* 1997, Dyer and Nobeoka 2000,

Yao et al. 2005, Fleisch and Tellkamp 2005, Byrne and Heavey 2006,) deals with the distorted information problem, i.e. information processing hurdles.
Notwithstanding this great attention of academicians and practitioners on the drawbacks which the lack of collaboration can result in, on the hurdles to collaboration that represent the main causes of such a lack and on how these hurdles can be overcame, the fundamental subject of what produces the need of collaboration has been almost neglected and only few works are focused on it.
With reference to them, Simchi-Levi *et al.*(2001) propose that the way to assure collaboration among the nodes of a logistic network pertains to the supply chain management area, whereas the level of collaboration required is a consequence of the decisions concerning the network structure. Without drawing a formal model, they state that the degree of collaboration needed, which according to them can be approximated by the number of stock-outs at the retailer stage, depends on the decisions taken in terms of number of supply chain stages, sourcing strategies, nodes' capacity and localization.
Also Helbing and Lammer (2005) face the problem of the network structure as a determinant of supply chain dynamics. In particular, since the relevance of topological features for the dynamic behavior of metabolic networks, food webs and cascade failures of power grids is commonly accepted, they assume that a similar relation is present in logistic networks too. In more detail, they develop a model focused on the dynamical property and linear stability of supply chains in dependence of the network topology, which, according to them, is given by the number of stages of the supply chain and by the sourcing strategy of each node only. The model they propose is based on conservation equations describing the storage and flow of inventories by a dynamic variant of Leontief's classical input-output model and on a set of equations that reflects the delayed adaptation of the production rate to some inventory-dependent desired production rate. By means of such a model they demonstrate that the logistic network topology, represented by the supply chain matrix (which synthesizes the number of stages of the supply chain, as well as the links among the supply chain nodes), has a direct influence on determining an over-damped or damped oscillatory behavior of the system expressed in terms of the eigenvalues of the Jordan matrix corresponding to the considered supply chain matrix.
Notwithstanding the relevance of the work of Helbing and Lammer (2005), on one hand, it does not link the dynamical behavior of the network with the degree of collaboration required among its nodes and, on the other hand, it considers only two supply chain design elements, i.e. number of stages of the network and sourcing strategies of each nodes.
On the contrary, Simchi-Levi *et al.* (2001), who take into account also nodes' capacity and localization, do not formalize their statement in any analytical model and, as a consequence, they do not demonstrate its validity.
For these reasons, the issue of clarifying the causes of the need for collaboration among the entities a supply chain is composed of is still topical; therefore, next section presents and validates a causal diagram devoted to explain the relation between all the topological features of a logistic network and the need for collaboration among its nodes. Here it is worth to notice that, due to the complexity of the subject, this work is focused on pull-based supply chains only and push-based logistic network will be faced in a subsequent research.

3. The proposed model

The aim of our model is to express the relationships between the decisions of supply chain design and the need for collaboration among the nodes of pull-based logistic networks by developing a causal diagram. As in Persson and Olnagher (2002), by supply chain design we mean all the decisions concerning the definition of the structure of the chain, so supply chain design does not include planning and control related decisions. Therefore all the decisions of supply chain management are out of the scope of this research.

3.1 Variables and relationships

The independent variables of our model are the decisions of supply chain design. As already stated, we will focus on the following decisions:

1. multiple sourcing: the number of sources each node will buy from. This means to decide whether to adopt a multiple or a single sourcing strategy;
2. splitting: this variable represents the decision of supply network design to install a certain quantity of inventory capacity at a certain node and to activate a certain number of nodes;
3. distance between nodes: this variable is connected to the localization of the nodes. We will express this variable in terms of distance between nodes;
4. number of levels (of the logistic network), e.g. a supply chain composed by *n* retailers and *m* manufacturers is a two stages supply chain.

The dependent variables of our model are number of stock-outs at the retailer stage, number of entries in the stock-out status and the stock-out quantity. These three variable are used to express the need for collaboration (Simchi-Levi *et al.* 2001).

We will outline the relationships between the independent and the dependent variables by a causal diagram where we will introduce system variables that are impacted by decisions in supply chain design and that impact stock-out levels. We will indicate whether the impact is 'positive' - that is when a variable is increasing/decreasing the impacted one is increasing/decreasing accordingly - or 'negative'.

We do not outline feedbacks from the system variables to the supply chain design variables, because in this research we are interested in investigating the need for collaboration that is generated by network design decisions.

3.2 Hypothesis

The system under consideration is a pull-based supply network. Each node of the supply network runs its facility based on a make-to-stock (MTS) strategy. Every node carries its inventories based on an economic order quantity (EOQ) management policy, specifically a (s,S) policy.

The EOQ and the safety stock (SS) are calculated based on demand forecast and on lead time forecast.

The replenishment lead time is basically a transportation lead time, so we can assume that replenishment lead time is a stochastic variable that is the sum of independent stochastic variables, in this case transportation lead times to carry the material from one node to another. This means that when the average replenishment lead time is increasing, than the replenishment lead time standard deviation is increasing accordingly.

At the retailer stage, every time an item is not in inventory when the customer order arrives, the order for that item is lost, and a 'stock out' is generated. While, when an order arrives at any other stage but the retailer, and there is not enough inventory to satisfy the order, the system generate a 'backlog' order and this order will be fulfilled as soon as the item is again in inventory.

Every node of the network aims at maximize its capacity utilization. If the downstream nodes do not fulfill its capacity, the node will sell its products also to nodes 'external' to the network. We hypothesize that the capacity installed at each node can not be higher that the total capacity installed at the upstream level. Moreover we hypothesize that it is not possible to install at a certain level redundant capacity.

3.3 Model description

Based on the above hypothesis, we develop the causal diagram in figure 1.

According to us, the performances of the entire network, in terms of stock-out units, number of stock out entries and number of stock outs , should be considered when assessing the need for collaboration. As stated in the hypothesis each node behaves in the same way (MTS strategy and EOQ model).

We will outline the effects of four decision variables, that are independent, on three dependent variables. In particular, as stated above, the independent variables are ‘multiple sourcing’, ‘distance between nodes’, ‘splitting’ and ‘number of levels’ of the network, whereas the dependent variables are ‘number of stock-outs at the retailer stage’, ‘stock-out quantity’ and ‘number of entries in the stock-out status’.
The diagram is divided in two parts:

- model 1: impacts on number of entries to stock-out status (figure 1.a);
- model 2: impacts on quantity of stock-out when in ‘stock-out’ status (figure 1.b);

In the following paragraph the two models are described in details.

3.3.1 Model 1: impacts on number of entries to stock-out status

This model describes the relations between the independent variables and the number of times a node (retailer) enters the stock-out status.

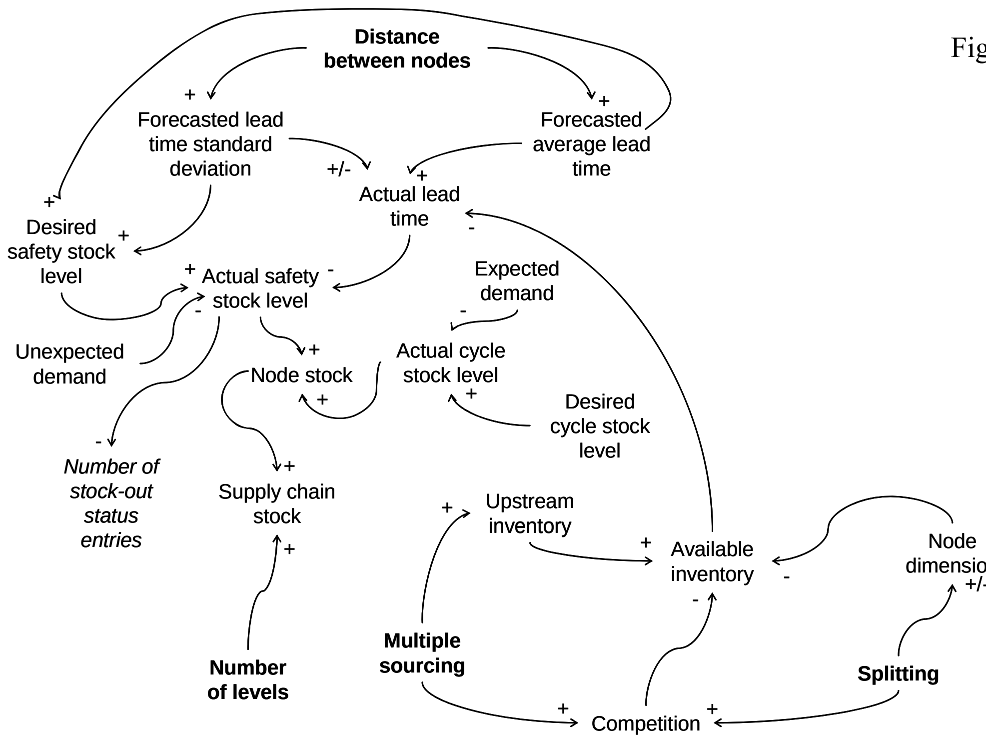

Figure 1.a – Model 1

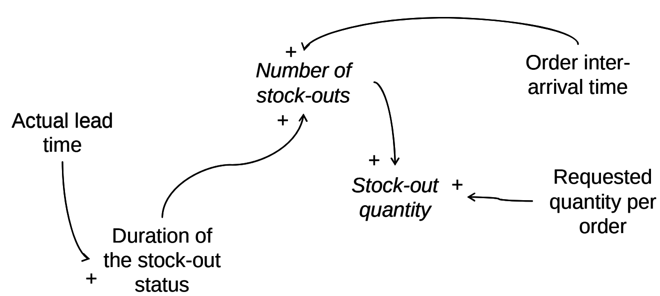

Figure 1.b – Model 2

Figure 1 – Proposed model (causal diagram)

Starting from describing in detail the relations for 'multiple sourcing', we define 'upstream inventory' as the sum of the inventory of the nodes which the generic node 'i' buys from. By definition, if a node buys from more than one supplier, the 'upstream inventory' increases, and so the 'available inventory' that node 'i' will have at its disposal when it emits an order will increase accordingly.
On the other side, under the above stated hypothesis, if the generic node 'i' buys from more that one supplier, each supplier, to maximize its capacity utilization, will sell to other customers. This will increase the level of 'competition' between the customers (nodes) at the same level. The higher the 'competition', the lower the amount of the shared resourced for each, so the lower the 'available inventory' for node 'i'. Summarizing, 'multiple sourcing' has a double effect on 'available inventory': one positive and another one negative.
The 'available inventory' has an impact on the replenishment lead time: when the 'available inventory' increases, the 'actual lead time' decreases. 'Actual lead time' is the lead time that the system experiences: this could be different from the forecasted one, although, if we assume that the forecast is quite reliable, 'actual lead time' is linked to the forecasted one. If the 'forecasted average lead time' is high, we expect that 'actual lead time' is high too and the variability we expect for 'actual lead time' is connected, positively or negatively, on 'forecasted lead time standard deviation'.
Total stock at each node ('node stock') can be divided into cycle stock, safety stock and stock in transit. According to the EOQ model, cycle stock are used, and are calculated, to satisfy the average (forecasted) demand while safety stock are used to manage demand fluctuations. Desired safety stock are calculated based on the classical formula that considers, among the others, forecasted average lead time as well as forecasted lead time standard deviation, and by using the EOQ formula desired cycle stock are calculated too. In a theoretical pull system where actual demand is equal to forecasted demand and lead time is deterministic, material is always available. In real system, actual demand fluctuates and so lead time, as it depends on the actual availability of material in the system. In our model we do not adjust the value of average lead time, standard deviation of lead time, since in the present work we do not want to understand the feasibility and the effectiveness of reduction strategies such as average lead time, lead time standard deviation and safety stock adjustment or client–supplier collaboration practices (if we found a relation between a supply chain design variable and the need for collaboration, further researches could analyze the effectiveness of supply chain management practices to reduce the negative impact). For this reason, we specify the variables: 'desired safety stock level' and 'desired cycle stock level' and the variable 'actual safety stock level'.
The 'actual safety stock level' depends positively on the 'desired safety stock level', but as the 'actual lead time' is different from the forecasted one, 'actual safety stock level' decreases if 'actual lead time' is increasing.
We assume that there is not a 'desired stock in transit level' as formally in the EOQ model it is not defined; however, we isolate a variable called 'stock in transit'. The quantity of stocks that is in transit is connected to the 'actual lead time': the higher the time needed to deliver an item, the higher the quantity of stock in transit.
Finally, the system enters in the stock-out status if the 'actual safety stock level' is not enough to absorb the un-forecasted variability in the demand. If the level of safety stock is low, than the probability to enter the stock-out status increases.
Concerning the variable 'distance between nodes', the decisions to localize the nodes in different place impacts the 'forecasted average lead time' and the 'forecasted lead time standard deviation'. Through these variables, distance impacts on 'actual lead time' as already explained.
With reference to 'splitting', this variable represents a decision that is twofold: on one side it answers to the question 'how many nodes are activated at a certain level?', on the other it answers to 'how much inventory capacity is installed at a certain node?'. It means that on one side it impacts the level of 'competition' that is present among the nodes of the level, and - as this last variable has been already

introduced when describing 'multiple sourcing' - we affirm it impacts negatively on the 'available inventory'. On the other side it impacts the dimension of each node ('node dimension'): evidently the sign of the impact for each node could be positive or negative whether is the case of a node big or small.
If the node is small, the probability to find material available is higher than in case of big node, because smaller orders have higher probability to be fulfilled. This is due to the fact that we assume the nodes do not implement any kind of collaborative practices, such as 'reserved capacity'. Under this hypothesis, all the nodes are served using the available stock. This effect has been expressed in our model by the negative arrow from 'node dimension' to 'available inventory'.
Finally, concerning the 'number of levels', each node of the network carries its inventory using a pull-based-system and, in this scenario, the 'number of levels' does not impact the number of stock-outs at the retailer stage. While, as adding a level means adding nodes to the network, the number of levels influences positively the number of nodes in the network and this physiologically influences the level of stock in the entire network.

3.3.2 Model 2: impacts on quantity of stock-out when in stock-out status

When a retailer enters the stock out status, it stays in this status as long as new materials do not arrive. However, the retailer can have zero inventory, but it does not necessarily receive orders: in this case no stock out is registered. The total amount of stock outs, that is one of the dependent variables we are monitoring, depends on the fact that the retailer enters the stock out status, and on how much time it stays in such a status and how many orders arrive during this period of time. We represent this by indicating that the 'number of stock-outs' is influenced positively by the 'duration of the stock-out status' as well as by the frequency of the demand ('order inter-arrival time') and the 'stock-out quantity' is influenced positively by both the 'number of stock-outs' and the 'requested quantity per order'.
Moreover, the 'duration of the stock-out status' depends, each time a retailer enters the stock out status, on the 'actual (replenishment) lead time' the retailer is experiencing. So 'actual lead time' is the link between model 1 and model 2, through this link we might see the effects on the number of stock out of the independent variables.

4. Model validation

The causal diagram presented in figure 1 is validated in the next paragraphs by studying through simulation techniques and statistical analyses the effects of each topological feature on a particular pull-based supply chain (hereinafter identified also as 'base case'). Before describing such a logistic network (paragraph 4.1) and the validation procedure (paragraph 4.2), here it is worth to notice that the use of a particular supply chain must not be considered as a limit. As a matter of fact, the aim of the section is to verify the hypothesized relations between topological features and the need for collaboration (i.e. the dynamic behaviors corresponding to the arrows and signs depicted in figure 1). Moreover, to investigate the magnitude of such relations is out of the scope of the work. As a consequence, an inductive approach can be used.

4.1 The supply chain of the 'base case'

To contain the level of complexity, a single-item, 3-stage supply chain is used as 'base case' for validating the model proposed in section 3. In particular, the considered logistic network, which has been drawn from the literature (Rossi *et al.* 2005), is supposed to belong to the fast moving consumer goods sector and is composed of: 1 retailer, 1 distributor and 1 manufacturer.
Concerning the retailer, it should be noted that no promotions are carried out and the replenishment policy referred to is the EOQ model, coherently with the hypothesis done in paragraph 3.2. In more

detail, the elements characterizing the retailer are: daily demand (which is given by the probability distributions of the customers inter-arrival time and of the number of items bought by the single customer), economic order quantity, re-order point, safety stock and forecasted supplier delivery lead times (represented by the probability distributions of the time the retailer has to wait to receive goods). The distributor too manages its inventories according to the EOQ model. Therefore, it is characterized by the same elements previously defined for the retailer (the only exception is represented by the absence of the parameter 'daily demand': as a matter of fact, for the distributor, the demand is given by the retailer orders).
As far as the manufacturer is concerned, when inventory falls until the reorder point, production campaigns are activated. As a consequence, the important elements to consider are: lot sizing policy, level of stock which triggers the production campaign and production lead time.
A synthetic view of the logistic network representing the 'base case' is given in table 1, which shows expressions and values of each element characterizing the supply chain nodes.

Table 1 – Synthetic view of the 'base case' supply chain

	ELEMENT	*EXPRESSION/ VALUE*
Retailer	Customers inter-arrival time	exp(0.0069) [days]
	Items bought by the single customer	abs(int(norm(6,3))) [units]
	Initial inventory	6.500 [units]
	Economic order quantity	$(2*a*Dr/h)^{1/2}$ = 7.146 [units]
	Re-order point	dr*LTr + SSr = 2.419 [units]
	Safety stock	$k*(\sigma^2_{dr}*LT+\sigma^2_{LTr}*dr^2)^{1/2}$ = 814 [units]
	Supplier delivery lead time	norm(2,0.5) [days]
Distributor	Initial inventory	11000 [units]
	Economic order quantity	$(2*a*Dd/h)^{1/2}$ = 10.143 [units]
	Re-order point	dd*LTd + SSd = 5.009 [units]
	Supplier delivery lead time	norm(2,0.5) [days]
Manufacturer	Initial inventory	20.000 [units]
	Lot size	30.000 [units]
	Stock level which activates the production of 1 lot	12.000 [units]
	Production lead time	5 [days]

4.2 The validation procedure

The validation phase is performed by building the simulation model of the 'base case' logistic network as well as of the logistic networks which can be obtained from the original one by modifying a single aspect of supply chain design. In particular, 7 simulation models have been built; the logics they are based on are shown by the stocks and flows diagram of the Appendix β, whereas the supply chains and the topological features each of them represents are depicted in tables 2.a and 2.b. Here it is worth to notice that the simulation models do not have any relation with the causal diagram previously introduced, i.e. they are not derived from it even if they are characterized by the same dependent variables (stock-outs at the retailer stage, number of entries in the stock-out status and stock-out quantity). As a matter of fact, such models have been obtained by putting into a simulation language the replenishment logics according to which the pull-based supply chains in exam are managed as well as the resources and the topological feature they are characterized by (see Appendix β).
With reference to the experimental campaigns, for each simulation model, i.e. for each supply chain design element, we perform an experimental campaign consisting of 100 simulation runs characterized by a 180-day length. Since the aim is to validate arrows and signs depicted in figure 1, the variables

chosen as benchmarks are, for each node, the lead time of the single order and the daily stock level and, for the nodes at the retailer stage only, the number of entries in a stock-out status, the number of stock-outs and the stock-out quantity (see table 3 for a synthesis of the experimental campaigns). In this way it is possible to analyze the effects that each topological feature has on the benchmark variables thus validating the causal diagram.

Table 2.a – Synthetic view of the used simulation models

	Topological feature	*Supply chain nodes*	*Nodes characteristics*	*External nodes*	*Nodes characteristics*	*Links*
Simulation model 1	none	retailer (a) distributor (b) manufacturer (c)	see table 1 see table 1 see table 1			(a)-(b); (b)-(c)
Simulation model 2	multiple sourcing	retailer (a) distributor1 (b) distributor2 (c) manufacturer1 (d) manufacturer2 (e)	see table 1 see table 1 (distributor) see table 1 (distributor) see table 1 (manufacturer) see table 1 (manufacturer)	retailer1 (f) retailer2 (g)	customer inter-arrival time: exp(0.0069) requested quantity: abs(int(norm(3,1))) EOQ=3.585 [units] ROP=613 [units] SS=209 [units] LT=norm(2,0.5) [days]	(a)-(b); (a)-(c); (f)-(b); (g)-(c); (b)-(d); (c)-(e)
Simulation model 3	multiple sourcing	retailer (a) distributor1 (b) distributor2 (c) distributor3 (d) manufacturer1 (e) manufacturer2 (f) manufacturer3 (g)	see table 1 see table 1 (distributor) see table 1 (distributor) see table 1 (distributor) see table 1 (manufacturer) see table 1 (manufacturer) see table 1 (manufacturer)	retailer1 (h) retailer2 (i) retailer3 (l)	customer inter-arrival time: exp(0.0069) requested quantity: abs(int(norm(3.3,1))) EOQ=4.793 [units] ROP=1.095 [units] SS=374 [units] LT=norm(2,0.5) [days]	(a)-(b); (a)-(c); (a)-(d); (h)-(b); (i)-(c); (l)-(d); (b)-(e); (c)-(f); (d)-(g)
Simulation model 4	multiple sourcing	retailer (a) distributor1 (b) distributor2 (c) distributor3 (d) distributor4 (e) manufacturer1 (f) manufacturer2 (g) manufacturer3 (h) manufacturer4 (i)	see table 1 see table 1 (distributor) see table 1 (distributor) see table 1 (distributor) see table 1 (distributor) see table 1 (manufacturer) see table 1 (manufacturer) see table 1 (manufacturer) see table 1 (manufacturer)	retailer1 (l) retailer2 (m) retailer3 (n) retailer4 (o)	customer inter-arrival time: exp(0.0069) requested quantity: abs(int(norm(3.7,1))) EOQ=5.360 [units] ROP=1.361 [units] SS=460 [units] LT=norm(2,0.5) [days]	(a)-(b); (a)-(c); (a)-(d); (a)-(e); (l)-(b); (m)-(c); (n)-(d); (o)-(e); (b)-(f); (c)-(g); (d)-(h); (e)-(i)
Simulation model 5	splitting	retailer1 (a) retailer2 (b) distributor (c) manufacturer (d)	customer inter-arrival time: exp(0.0069) requested quantity: abs(int(norm(6,3))) demand per retailer: 50% EOQ=5.050 [units] ROP=1.219 [units] SS=418 [units] LT=norm(2,0.5) [days] see table 1 (distributor) see table 1 (manufacturer)			(a)-(c); (b)-(c); (c)-(d)

Table 2.b – Synthetic view of the used simulation models

	Topological feature	*Supply chain nodes*	*Nodes characteristics*	*External nodes*	*Nodes characteristics*	*Links*
Simulation model 6	number of levels	retailer (a) distributor (b) manufacturer (c) manufacturer1 (d)	see table 1 see table 1 EOQ=30.000 [units] ROP=12.000 [units] LT=5 [days] lot size=45.000 [units] stock level which activates the production of 1 lot=18.000 [units] production LT=5 [days]			(a)-(b); (b)-(c); (c)-(d)
Simulation model 7	distance between nodes	retailer (a) distributor (b) manufacturer (c)	customer inter-arrival time: exp(0.0069) requested quantity: abs(int(norm(6,3))) EOQ=7.146 [units] ROP=3.614 [units] SS=1.207 [units] LT=norm(3,0.75) [days] see table 1 see table 1			(a)-(b); (b)-(c)

Applying ANOVA and/or linear regression to these results allows the link among each of the supply chain design elements and the benchmark variables to be statistically valuated (Green 2000) and, as a consequence, the proposed model for explaining the relation between the logistic network topological features and the need for collaboration among nodes to be validated.
In the following paragraphs the statistical analyses performed on the simulation models outputs are presented and the results obtained are commented.

Table 3 – Synthesis of the experimental campaigns

<table>
<tr><th>Experimental campaign</th><th>Simulated case</th><th>Simulation model used</th><th>Observed variables</th><th>Number of runs</th><th>Run length</th></tr>
<tr><td>1</td><td>base case</td><td>1</td><td rowspan="7">lead time of the single order
daily stock level of each node
number of entries in a stock-out status (retailer stage)
number of stock-outs (retailer stage)
stock-out quantity (retailer stage)</td><td rowspan="7">100</td><td rowspan="7">180 [days]</td></tr>
<tr><td>2</td><td>multiple sourcing case (2 different sources for the retailer)</td><td>2</td></tr>
<tr><td>3</td><td>multiple sourcing case (3 different sources for the retailer)</td><td>3</td></tr>
<tr><td>4</td><td>multiple sourcing case (4 different sources for the retailer)</td><td>4</td></tr>
<tr><td>5</td><td>splitting case (2 retailers each of them satisfied the 50% of the original demand)</td><td>5</td></tr>
<tr><td>6</td><td>number of levels case (4 different stages)</td><td>6</td></tr>
<tr><td>7</td><td>distance between nodes case (the distance between retailer and distributor is the 150% of the original one)</td><td>7</td></tr>
</table>

4.3 Multiple sourcing relationships validation

Concerning the supply chain design element ‘multiple sourcing’, the relations which it is supposed to be involved in and the results of the performed statistical analyses are summarized in table 4.
According to our model, the sign of the relation between ‘multiple sourcing’ and ‘number and quantity of stock outs’ depends on the sign of the relation ‘multiple sourcing’-‘actual lead time’. This sign is *a priori* unpredictable, because it depends on the relative weight of the variables ‘upstream inventory’ and ‘competition’ (see fig.1). To evaluate the sign of this relation, we perform a one-way ANOVA, whose results can make us infer that ‘actual lead time’ tends to decrease while the ‘multiple sourcing’ level is increasing. As the relation between ‘available inventory’ and ‘actual lead time’ is negative (see figure 1) we might observe that in our supply chain, for the multiple sourcing tested levels, when the number of sources is increasing, the positive effect of ‘upstream inventory’ on ‘available inventory’ is greater than the negative effect of ‘competition’ at the same level.
Concerning the relation between the supply chain design variable under analysis and the need for collaboration (i.e. the number and quantity of stock outs), we hypothesize that if ‘actual lead time’ is increasing, the ‘number of stock-outs’ and the ‘stock-out quantity’ increase as well. Analyzing the results of the ANOVA, we observe that there is no statistical evidence that the level of ‘multiple sourcing’ impacts the ‘number of stock-outs’ as well as the ‘stock-out quantity’, as the p-values are

quite high (0.45 and 0.51). Nevertheless we observe that there is the tendency for higher levels to have higher stock outs.
It is interesting to notice, that for what concerns the relation between the level of ‘multiple sourcing’ and the ‘number of stock-out status entries’ at the retailer stage, there is statistical evidence (p-value=0.045) that when the ‘multiple sourcing’ level increases the number of entries in the stock-out status decreases.

Table 4 – Results of the statistical analyses referred to the ‘multiple sourcing’ relationships validation

Relation	*Hypothesized sign*	*Test (α = 0.05) and result*	*Verified sign*
Available inventory-Actual lead time	-	Regression R= 62%	-
Multiple sourcing-Actual lead time	+/-	One-Way ANOVA p-value =0	-
Multiple sourcing-Node (retailer) stock	-/+ (opposite to lead time sign)	One-Way ANOVA p-value=0	+
Multiple sourcing-Number of stock-out status entries (at the retailer stage)	+/-	One-Way ANOVA p-value1 = 0.196 p-value2 = 0.045	-
Multiple sourcing-Number of stock-outs	+/-	One-Way ANOVA p-value=0.45	?
Multiple sourcing-Stock-out quantity	+/-	One-Way ANOVA p-value=0.51	?

4.4 Splitting relationships validation

Concerning the supply chain design element ‘splitting’, the relations which it is supposed to be involved in and the results of the performed statistical analyses are summarized in table 5.
As far as the relation between ‘splitting’ and the need for collaboration (expressed by the ‘number and quantity of stock outs’) is concerned, from the result of the ANOVA (p-value = 0), we can infer that when the level of splitting is increasing the need for collaboration is increasing accordingly.
It is worth of notice that, as in the case of multiple sourcing (see 4.3), the sign of the relation between ‘splitting’ and ‘number of stock outs’ as well as ‘quantity of stock outs’ depends on the sign of the relation between ‘splitting’ and ‘actual lead time’. However, we observed that, unlikely the case of multiple sourcing, here it is possible to affirm that when the ‘actual lead time’ is increasing the total stock-outs are increasing too. As we have outlined above, in the case of the ‘multiple sourcing’ design element the ‘actual lead time’ is decreasing but it is not evident an effect on the total amount of stock-out (even a tendency of increasing in the number of stock-outs at the increasing of the level of ‘multiple sourcing’ can be observed). In the case of the ‘splitting’ design element, instead, the effect is evident and can be detected with ANOVA. To explain such difference, we perform a T-test for the difference of the means of two sample populations. In this case the two samples are the retailer lead time values for each of the 100 replications calculated in the case of 1 distributor and 1 retailer, ’base case’ (simulation model 1), and in the case, respectively, of multiple sourcing with 2 distributors (simulation model 2) and splitting (simulation model 5). We observe that in the case of multiple sourcing the difference between the average lead time of ’base case’ and multiple sourcing is |0.3|. In the case of splitting the difference is |1.2|. We think that this difference in the magnitude of the effect is the cause for not registering the impact of lead time variation on number and quantity of stock outs in the case of multiple sourcing.

Table 5 – Results of the statistical analyses referred to the 'splitting' relationships validation

Relation	*Hypothesized sign*	*Test (α = 0.05) and result*	*Verified sign*
Splitting-Actual lead time	+/-	One-Way ANOVA p-value = 0.012	+
Splitting-Node (retailer) stock	-	One-Way ANOVA p-value = 0	-
Splitting- Number of stock-out status entries (at the retailer stage)	+/-	One-Way ANOVA p-value = 0.032	+
Splitting- Number of stock-outs	+/-	One-Way ANOVA p-value = 0	+
Splitting-Stock-out quantity	+/-	One-Way ANOVA p-value = 0	+

4.5 Number of level relationships validation

We performed an ANOVA to test whether there is an impact of the number of level of the network on the stock out, the lead time and the average stock at the retailer (the data used for such an analysis are the outputs of the simulation models 1 and 6 respectively). As it can be inferred, there is no statistical evidence for the impact of the number of 'supply network levels' on the 'actual lead time' (p-value=0.91), on the 'node (retailer) stock' (0.868) and on the 'number of stock-outs' (p-value 0.995). This is due to the fact that the context under analysis is the pull-based one.

4.6 Distance between nodes relationships validation

Concerning the supply chain design element 'distance between nodes', the relations which it is supposed to be involved in and the results of the performed statistical analyses are summarized in table 6. The ANOVA shows that there is no statistical evidence (p-value= 0.920 and p-value = 0.929) that distance impacts on 'number of stock outs' and 'quantity of stock outs'. In our opinion this is due to the fact that both SS level and reorder point already take into account that the lead time increases and, with reference to the SS level only, that the lead time standard deviation increases accordingly.

Table 6 – Results of the statistical analyses referred to the 'distance between nodes' relationships validation

Relation	*Hypothesized sign*	*Test (α = 0.05) and results*	*Verified sign*
Distance between nodes (distributor and retailer)-Actual lead time	+	One-Way ANOVA p-value = 0	+
Distance between nodes (distributor and retailer)-Node (retailer) stock	+	One-Way ANOVA p-value = 0	+
Distance between nodes (distributor and retailer)-Stock in transit	+	One-Way ANOVA p-value = 0	+
Distance between nodes (distributor and retailer)-Number of stock-out status entries	?	One-Way ANOVA p-value = 0.062	-
Distance between nodes (distributor and retailer)-Number of stock-outs	+/-	One-Way ANOVA p-value = 0.920	?
Distance between nodes (distributor and retailer)-Stock-out quantity	+/-	One-Way ANOVA p-value = 0.929	?
Distance between nodes (distributor and retailer)-Node (distributor) stock	No effect	One-Way ANOVA p-value = 0.89	No effect

5. Conclusions and direction for future research

The aim of this paper is to propose a model for explaining the relations between supply chain design decisions and the need for collaboration among the nodes of a logistic network. As a matter of fact, even if the need for collaboration is experienced by many industries and the lack of collaboration between the actors of a supply chain is widely recognized as cause of several drawbacks, e.g. inventory costs amplification, longer replenishment lead times, etc. (Forrester 1961, Sterman 2000, Chopra and Meindl 2001), in the academic literature, the fundamental subject of what produces such a need has been faced by only few works.

According to Simchi-Levi *et al.* (2001) some of the root causes that influence the need for collaboration can be found in the domain of the supply chain design decisions: they affirm, without formalizing their statement in any analytical model and, as a consequence, without demonstrating its validity, that the degree of collaboration needed depends on the decisions taken in terms of number of supply chain stages, sourcing strategies, nodes' capacity and localization. Also Helbing and Lammer (2005) consider the network structure as a determinant of supply chain dynamics, however they do not link the dynamical behavior of the network with the degree of collaboration required among its nodes and, moreover, they take into account only two supply chain design elements, i.e. number of stages of the network and sourcing strategies of each nodes.

Starting from the intuitions of Simchi-Levi *et al.* (2001) and Helbing and lamer (2005), we want to formalize by a causal diagram the relations between the need of collaboration among the nodes of a pull-based logistic network and the supply chain topological features. In particular we focus on the relations between the approximation of the need for collaboration, i.e. the stock-outs that are experienced at the retailer stage (dependent variable), and four supply chain design decisions (independent variables) that are: 'multiple sourcing', 'splitting', 'distance between nodes' and 'number of levels' in the supply chain.

To validate the causal diagram we build several simulation models of pull-based supply chains where each actor runs its facility using the EOQ model and does not carry on any collaboration practices such as VMI, capacity reservation nor any adjustments to the EOQ forecasted parameters. We register the stock out numbers, the quantity of stock-outs and the times the retailers enter the stock-out status in different supply chain configuration situations, that means varying the level of the independent variables. By performing statistical analysis, i.e. ANOVA and linear regression, on the registered data we validate the existence of the majority of the hypothesized relations and the sign of such relations (see figure 1). In particular, even if we observe also for the 'multiple sourcing' element the tendency of a positive impact on the need for collaboration, we statistically demonstrate only for the 'splitting' supply chain design decision that if it increases the need for collaboration increases accordingly. Moreover, with reference to 'distance between nodes' and the 'number of levels' the ANOVA confirms that there is no statistical evidence that they impact on 'number of stock outs' and 'quantity of stock outs'. This is due to the fact that, concerning the former independent variable, the parameters of the EOQ model already take into account that both the lead time and the lead time standard deviation increase and, concerning the latter, that the context under analysis is the pull-based one.

We reckon that the proposed model presents some limitations. First of all not all the possible combinations of independent variables have been tested, secondly that it has been tested only in a pull-based environment and finally that it has been tested in the case of a supply chain carrying a single product, when it is evident that real supply chain should be designed to manufacture and transport a growing variety of products. It would be interesting to analyze whether there is a different effect of the supply chain design variables on the need for collaboration in different product contexts – e.g. innovative and functional products (Fisher 1997) or in different phases of the product life cycle (Vonderembsea et al. 2006) . We believe these could be further steps of the research.

Appendix β

In figure 10 and 11 the stocks and flows diagram and the equations which the simulation model 1 representing the 'base case' supply chain is composed of are depicted.

The simulation models representing the 'multiple sourcing', the 'splitting', the 'number of levels' and the 'distance between nodes' cases have been obtained exploiting the same logics simulation model 1 is based on and, as a consequence, they are not reported in terms of stocks and flows diagram and list of equations.

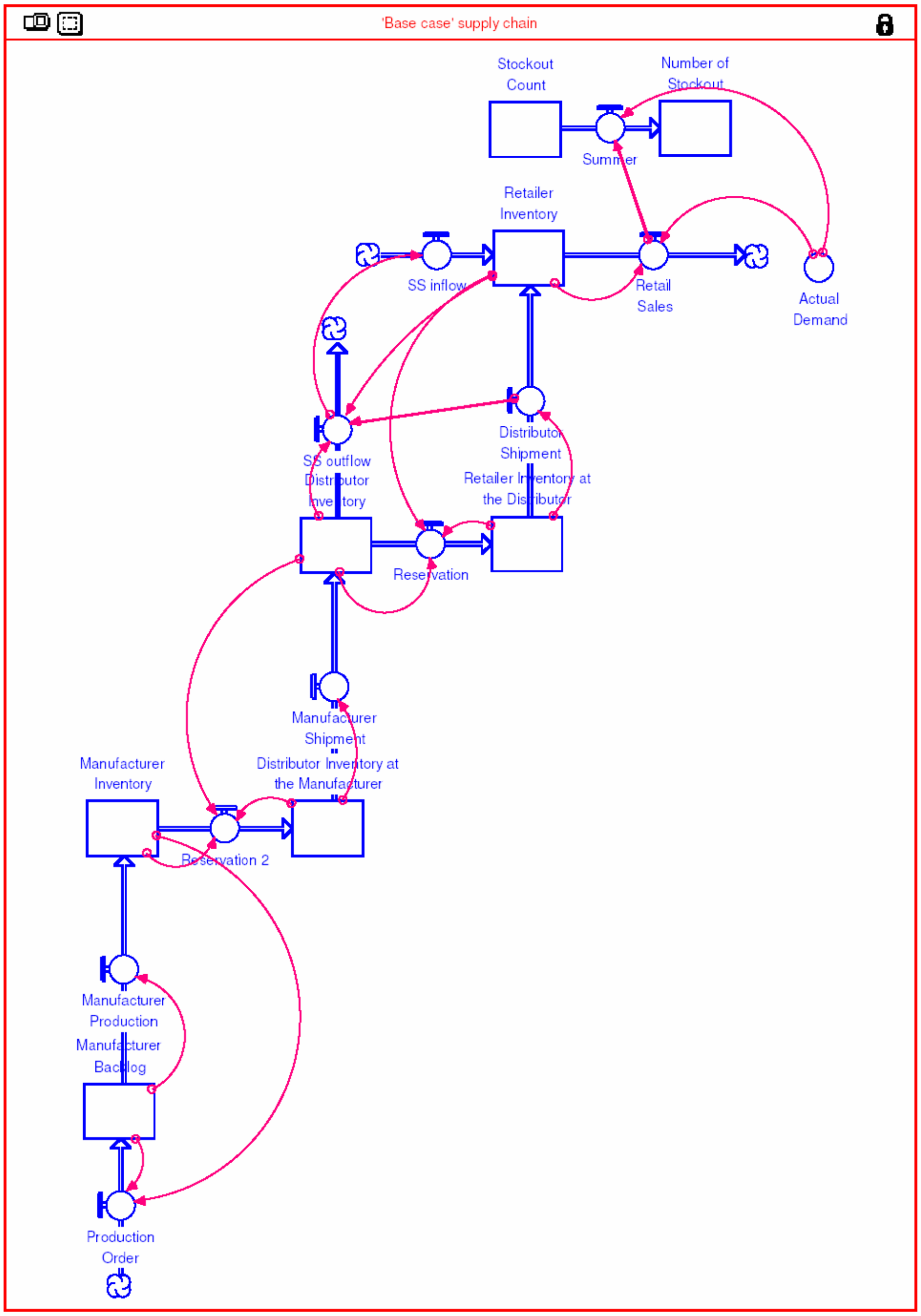

Figure 10 – Stocks and flows diagram describing the 'base case' supply chain

'Base case' supply chain

```
Distributor_Inventory(t) = Distributor_Inventory(t - dt) + (Manufacturer_Shipment - Reservation - SS_outflow) * dt
INIT Distributor_Inventory = 11000
 INFLOWS:
   Manufacturer_Shipment = DELAY(PULSE(Distributor_Inventory_at_the_Manufacturer),NORMAL(2,0.5))
 OUTFLOWS:
   Reservation = IF(Retailer_Inventory+Retailer_Inventory_at_the_Distributor>2419) THEN
   IF(Retailer_Inventory_at_the_Distributor<>0 AND Retailer_Inventory_at_the_Distributor<7146 AND
   Retailer_Inventory<=2419) THEN PULSE(MIN(Distributor_Inventory,7146-Retailer_Inventory_at_the_Distributor)) ELSE 0
   ELSE PULSE(MIN(Distributor_Inventory,7146))
   SS_outflow = IF(Retailer_Inventory<814 AND Distributor_Shipment<>0) THEN
   PULSE(MIN(814-Retailer_Inventory,Distributor_Inventory)) ELSE 0
Distributor_Inventory_at_the_Manufacturer(t) = Distributor_Inventory_at_the_Manufacturer(t - dt) + (Reservation_2 -
Manufacturer_Shipment) * dt
INIT Distributor_Inventory_at_the_Manufacturer = 0
 INFLOWS:
   Reservation_2 = IF(Distributor_Inventory+Distributor_Inventory_at_the_Manufacturer>5009) THEN
   IF(Distributor_Inventory_at_the_Manufacturer<>0 AND Distributor_Inventory_at_the_Manufacturer<10143 AND
   Distributor_Inventory<=5009) THEN
   PULSE(MIN(Manufacturer_Inventory,10143-Distributor_Inventory_at_the_Manufacturer)) ELSE 0 ELSE
   PULSE(MIN(Manufacturer_Inventory,10143))
 OUTFLOWS:
   Manufacturer_Shipment = DELAY(PULSE(Distributor_Inventory_at_the_Manufacturer),NORMAL(2,0.5))
Manufacturer_Backlog(t) = Manufacturer_Backlog(t - dt) + (Production_Order - Manufacturer_Production) * dt
INIT Manufacturer_Backlog = 0
 INFLOWS:
   Production_Order = IF(Manufacturer_Inventory<=12000 AND Manufacturer_Backlog=0) THEN PULSE(30000) ELSE 0
 OUTFLOWS:
   Manufacturer_Production = DELAY(PULSE(Manufacturer_Backlog),5)
Manufacturer_Inventory(t) = Manufacturer_Inventory(t - dt) + (Manufacturer_Production - Reservation_2) * dt
INIT Manufacturer_Inventory = 20000
 INFLOWS:
   Manufacturer_Production = DELAY(PULSE(Manufacturer_Backlog),5)
 OUTFLOWS:
   Reservation_2 = IF(Distributor_Inventory+Distributor_Inventory_at_the_Manufacturer>5009) THEN
   IF(Distributor_Inventory_at_the_Manufacturer<>0 AND Distributor_Inventory_at_the_Manufacturer<10143 AND
   Distributor_Inventory<=5009) THEN
   PULSE(MIN(Manufacturer_Inventory,10143-Distributor_Inventory_at_the_Manufacturer)) ELSE 0 ELSE
   PULSE(MIN(Manufacturer_Inventory,10143))
Number_of_Stockout(t) = Number_of_Stockout(t - dt) + (Summer) * dt
INIT Number_of_Stockout = 0
 INFLOWS:
   Summer = IF (Actual_Demand-Retail_Sales>0) THEN PULSE(1) ELSE 0
Retailer_Inventory(t) = Retailer_Inventory(t - dt) + (Distributor_Shipment + SS_inflow - Retail_Sales) * dt
INIT Retailer_Inventory = 6500
 INFLOWS:
   Distributor_Shipment = DELAY(PULSE(Retailer_Inventory_at_the_Distributor),NORMAL(2,0.5))
   SS_inflow = PULSE(SS_outflow)/1000
 OUTFLOWS:
   Retail_Sales = IF(Retailer_Inventory>=Actual_Demand/1000) THEN Actual_Demand ELSE PULSE(Retailer_Inventory)
Retailer_Inventory_at_the_Distributor(t) = Retailer_Inventory_at_the_Distributor(t - dt) + (Reservation - Distributor_Shipment) * dt
INIT Retailer_Inventory_at_the_Distributor = 0

 INFLOWS:
   Reservation = IF(Retailer_Inventory+Retailer_Inventory_at_the_Distributor>2419) THEN
   IF(Retailer_Inventory_at_the_Distributor<>0 AND Retailer_Inventory_at_the_Distributor<7146 AND
   Retailer_Inventory<=2419) THEN PULSE(MIN(Distributor_Inventory,7146-Retailer_Inventory_at_the_Distributor)) ELSE 0
   ELSE PULSE(MIN(Distributor_Inventory,7146))
 OUTFLOWS:
   Distributor_Shipment = DELAY(PULSE(Retailer_Inventory_at_the_Distributor),NORMAL(2,0.5))
Stockout_Count(t) = Stockout_Count(t - dt) + (- Summer) * dt
INIT Stockout_Count = 200000
 OUTFLOWS:
   Summer = IF (Actual_Demand-Retail_Sales>0) THEN PULSE(1) ELSE 0
Actual_Demand = PULSE((ABS(INT(NORMAL(6,3)))),0,EXPRND(0.0069))
```

Figure 11 – Equations describing the 'base case' supply chain

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