Risk analysis for cooperation policies benefits in reducing the bullwhip effect in a telecom supply chain

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RISK ANALYSIS FOR COOPERATION POLICIES BENEFITS IN REDUCING THE BULLWHIP EFFECT

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Abstract: supply chain demand is often prone to fluctuations and instability. Known as the "Bullwhip effect", small variations in end item demand create order and inventory oscillations that amplify from a downstream site to an upstream site. Applying a risk analysis approach, and assuming the bullwhip phenomenon as a constant reality, this paper will present the profits or losses that can accrue from various corporation policies. The latter are based on planning, information sharing and stock-adjustment strategies adopted by the supply chain actors. The system considered for this research is a four-stage supply chain. In order to allow risk measures and analysis a specific discrete-event-simulation system, was developed.

Keywords: Information, Simulation, Planning, Capacity, risk assessment.

1. INTRODUCTION

The bullwhip effect, i.e. the amplification of demand variability as one moves up in the supply chain, can be reduced by using cooperation policies (e.g. Moyaux, *et al.*, 2003; Lee and Whang, 2000; Xu, *et al.*, 2001). The purpose of this research is twofold: (1) to propose new cooperation policies based on planning strategies and information sharing strategies (2) to introduce a risk analysis approach in order to evaluate these policies.
The system focused on is a one product, four stages supply chain in which capacity decisions must be taken dynamically.
The paper is organized as follows: in the next section, we present a literature review, and then we present the system under study in section 3. Section 4 describes the simulation tool that support risk evaluation. Section 5 presents the risk analysis approach which leads us to the validation case and the related data description and characterisation in section 6. And then, in section 7, we focus on the results analysis. A summary, some final remarks and a description of future research conclude the paper.

2. A LITERATURE REVIEW

The bullwhip phenomenon has been identified and observed in industry for decades. The first academic research into the subject was probably by Forrester (1958). Later, Sterman (1989, 2000) offered a more nuanced rationalization of the phenomenon. Lee, *et al.* (1997) identifies four main causes of bullwhip effect as: demand signal processing, order batching, rationing game and price variation.
Fransoo and Wouters (2000) point out that several bullwhip measures can be used in a given supply chain. One way to do this is by considering the measurements of standard deviations of the upstream and the downstream supply chain demands.
Among ways to reduce the Bullwhip effect, supply chain literature and management practice focus on cooperation policies based on information sharing among supply chain members. Lee and Whang (2000), for instance, report that demand forecast and inventory information sharing is effective in reducing order fluctuations and safety stocks. Aviv (2001) using a two-echelon supply chain of a single product compares a policy where the retailer and the

supplier develop and employ a joint forecast, to a policy where each party develops and employs its own forecast. Moyaux, *et al.* (2003), using a multi-agent system approach, proposes a cooperation technique based on tokens. Xu, *et al.* (2001) analysed a cooperation scheme where the manufacturer performs the forecasting and ordering activities for both parties, i.e. for the retailer and the manufacturer itself. The impact of certain supply chain characteristics - especially lead-times and demand correlations between retailers - is also studied (e.g. Aviv and Federgruen, 1998.)

While analysing most of the previous literature, we noticed that the only points-of-view considered in reducing the bullwhip effect were based on information sharing and inventory adjustment approaches and finally on forecasting methods and techniques (e.g. Hanssens, 1998; Chen, *et al.*, 2000; Chen, *et al.*, 1999.) Cooperation policies, highlighting planning policies (e.g. policies based on capacity planning strategies) were little studied or ignored (see Småros, 2005). Moreover, for some applications like telecom supply chains, a risk analysis approach is more appropriate than the usual performance evaluation approaches because of the high uncertainty related to this supply chain environment.

The goal of this research is to analyse some cooperation policies focusing on: (i) capacity planning strategies (ii) inventory adjustment strategies and (iii) information sharing strategies using a risk analysis approach which is new in such context to the knowledge of the authors. This is done with a dedicated decision support system, based on discrete-event-simulation.

3. THE SYSTEM UNDER STUDY

The system under study is a telecom supply chain. Generally, this chain includes 4 categories of actors (see Figure 1.):

• the Global Operator (GO) is responsible for the network coverage deployment and the associated services provided to the customers,

• the Original Equipment Manufacturer (OEM) manufactures the different equipment (e.g. hard -drive, printers, monitors, portable phones …),

• the Contract Manufacturer (CM) resells the products it assembles to some partners who incorporated them in their own configurations and put them on the market under their own brand-name,

• the SemiConductor Supplier (SCS) manufactures the basic electronic components (chips) used by the CM.

Other characteristics of the telecom supply chain are (see Mahmoudi, *et al.*, 2004):

• the uncertainty of the demand: the emergence of new actors in the supply chain, the uncontrolled exchange of information, the difficulties involved in setting up reliable processes of cooperation and collaboration in the chain and the absence of contractual structures binding the actors of the chain, make the demand uncertain.

• instability: the demand is very sensitive to seasonal variation, the vagaries of fashion and national and international events.

• short life cycle products: rapid technological advances drastically reduce product's life cycle.

This underlines the need for cooperation policies between the supply chain actors, and shows the convenience of a risk approach for such supply chains operating in a very uncertain environment. These cooperation policies must be centred especially on capacity definition strategy due to the huge investments made to acquire new capacities especially for the semi-conductors suppliers (SCS). Also, they must be centred on stock adjustment strategies and information sharing.

In order to implement such cooperation policies, we propose for each actor of the supply chain a four process representation (see Figure 2. and section 4 for more details) that includes:

• the Sales & Operations Planning (S&OP) Process,
• the Medium Term Planning (MTP) Process,
• the Short Term Planning (STP) Process,
• and the Release & Inventory Management (R&IM) Process.

The definition of these processes gives the possibility to set up different cooperation policies. In this paper, they result from the combination of:

• forecast transmission strategies, more known as collaborative forecasting strategies,
• two parameters mainly affect the planning strategies:
  - whenever a change of the capacity is proposed, only a ratio of it is accepted: (p).
  - stock cover: (S_c).

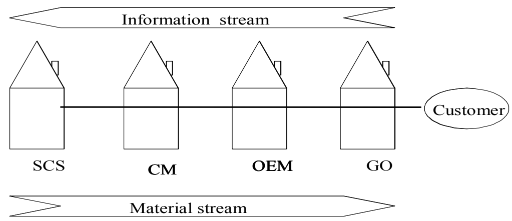

Fig. 1. Telecom Supply chain structure.

4. A SIMULATION TOOL TO SUPPORT RISK EVALUATION

The risk analysis approach adopted in order to evaluate the different cooperation policies described below, is supported by a simulation tool -called LogiRisk- It was developed using Perl Language[1]. This simulator is based on discrete-event-simulation modelling approach, and establishes a generic representation of the different planning processes for each actor of the supply chain (see Figure 2.):

• *The Sales & Operations Planning (S&OP) Process*: details the various decisions which are taken throughout the long term planning. Its most important outputs are the production capacities (see Figure 2.). This process, models (i) the forecast calculation, (ii) the interpretation behaviours the decision-maker exhibits when examining the received forecasts from his customers, (iii) the transmission behaviours when a decision-maker sends his forecasts to his supplier.

[1] The authors used the object oriented technology concept provided by Perl to design and to develop a prototype of the simulation tool, i.e. LogiRisk.

If there is no forecasted demand transmission, the S&OP process computes its forecasts internally using the Holt and Winters Smoothing Algorithm. Otherwise, it sums up the forecasts transmitted by the customers.

According to the demand forecasts, workload is computed and smoothed over several time periods. The resulting workload defines a capacity plan that must be validated by the S&OP manager. This latter has, in this study, a specific behaviour: he compares the proposed capacity plan with the one he validated in the previous S&OP process, and only accepts a given percentage (p) of capacity variation.

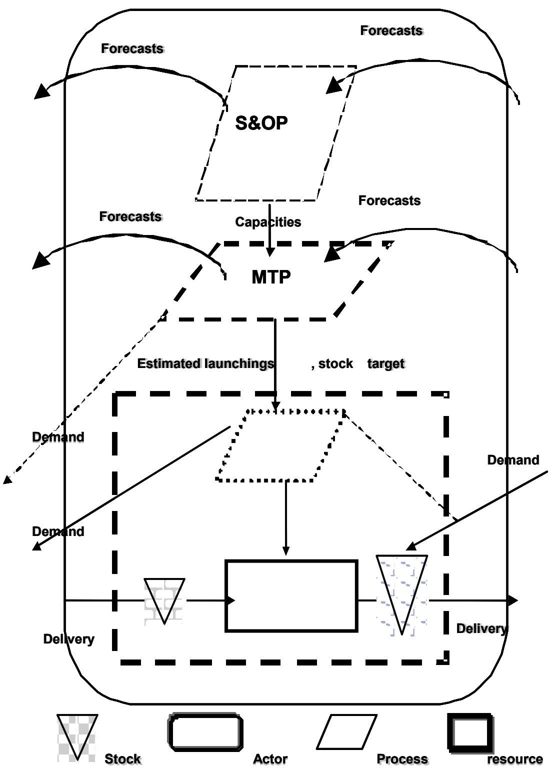

Fig. 2. The generic representation of the supply chain actors' processes.

• *The Medium Term Planning (MTP) process* computes the estimated production release of final products, the raw materials demand (push strategy) to send to the suppliers, or objective stock levels (pull strategy). As in the S&OP process, the demand forecast are updated either internally or aggregated from the demand forecast information received from the customers.

• *The Short Term Planning (STP) and the Release & Inventory Management (R&IM) processes* details together the various short term decisions.

The STP process takes good account of the actor's own constraints (i.e. breakdowns,…), the calculation of the possible production release and, in cases of a pull strategy, the demand to send to the suppliers.

The R&IM process is responsible for taking into account the other actors' constraints (i.e. insufficient delivery,…), the products inventories update, the calculation of the real production release, and, finally, the calculation of the quantities to be delivered to each customer.

Note that these four processes are not made at the same frequency and do not use information (forecasts, production, capacity) aggregated with the same time granularity. Equations that give the details of the model characterising the S&OP, the MTP, the STP and the R&IM processes are given by Mahmoudi, *et al.* (2006).

5. THE RISK ANALYSIS APPROACH

The cooperation strategies described in section 3 face several possible market scenarios. In the following study the scenarios depend on two uncertain parameters:

• a seasonnality growth of the market percentage : (τ).

• a standard deviation of the normal distribution relating demands and forecasts : (σ).

As a risk oriented approach is chosen, the probability indexes or ranks (subjective probability are used because of the decision-maker's inability to determine objective probabilities) of these scenarios are evaluated according to the decision-makers expertise using a five-rank scale given by the Table 1.

Table 1 Probability assessment scale.

Index	Subjective estimate	Description
1	Very unlikely	Very rare event
2	Improbable	There is indirect evidence of event
3	Moderate	There is direct evidence of event
4	Probable	There is strong direct evidence of event
5	Very probable	Event recurs frequently

For a given cooperation policy and for each scenario two types of criticalities are analysed: (i) a criticality related to the generated costs (C_1); and (ii) a criticality related to demand variability amplification (C_2).

The first criticality, C1, is the result of the multiplication of the scenario probability index by the supply chain total cost. This total cost is the sum of:

• release costs: the costs of production release,

• capacity acquisition costs: the costs associated with the acquisition of new capacities,

• stock holding costs: the costs of keeping stocks,

• and stock-out costs: the costs of the stock-outs that occur when the supply chain has no finished products to satisfy the market demand.

The second criticality, C2, deals with the demand variability amplification. This indicator is the result of the quotient of the standard deviations associated respectively with the upstream, and the downstream, supply chain demands.

All these indicators are computed along the simulated horizon. This leads us to the definition of the considered policy risk table (see Table 2.). The risk related to the considered cooperation policy in terms of costs is a function $f(\textit{scenarios criticalities})$ characterizing the decision-maker risk assessment criterion.

The risk in terms of demand variability is computed in the same way.

Table 2 A Risk table of a given cooperation policiy.

Market scenarios	Proba-bility indexes	Total Cost	Standard deviation quotient	Criticality C_1	Criticality C_2
Scenario 1	p_1	x_1	y_1	X_1	Y_1
Scenario 2	p_2	x_2	y_2	X_2	Y_2
Scenario i	p_i	x_i	y_i	$X_i = x_i * p_i$	$Y_i = y_i * p_i$
Scenario n	p_n	x_n	y_n	X_n	Y_n
SC cooperation policy risks				$f(X_1, X_2, \ldots X_n)$	$f(Y, Y_2, \ldots X_n)$

In this paper $f(.)$ is the sum of the criticalities of the different scenarios and measures a mean cost or amplification. Notice that we might have use other functions $f(.)$ (e.g. $f(X_1, X_2, ..., X_n) = \min_i (X_i)$ or $f(X_1, X_2, ..., X_n) = \max_i (X_i)$) to characterise others risk evaluation methods.

6. THE EXPERIMENTAL VALIDATION

In order to validate the approach, a case study is chosen. It deals with a four stage telecom supply chain with a single product (see Figure 1.)

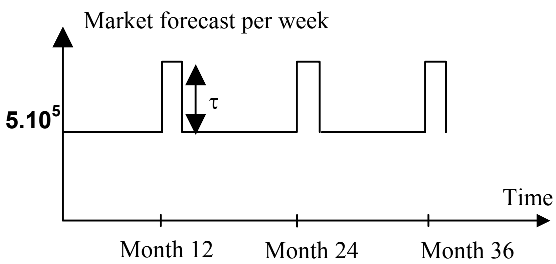

Fig. 3. shape of the market forecast.

The data used in experiments are summarised below:

• Stock covers (S_c) : the evaluated values are 0, 1, 2, 3, 4, 5. These stock covers are expressed in weeks of the forecasted demand estimated or received by and actor.

• Capacity strategy: the analysed strategy consists in accepting only a ratio (p) of a proposed change of capacity : p = 50%, p = 75%,p = 100%.

• Information sharing: two kinds of collaborative forecasting strategies: with and without forecast transmission.

• Market scenarios: The forecast shape of the market is given by Figure 3. Let's note that the market is globally stable. But, the concurrence evolutions and market sharing variations make the demand so fluctuant. Due to this fact, we propose to compute the market demand using a normal distribution centred on the market forecast. Moreover, the shape is coherent with the fact that in December demand has a high seasonality. Therefore, the market demand evolution scenarios result from the combination of the following cases:

- demand ramp-up in December τ: low:10%, average: 50%, high: 100% (calculated relatively to the demand of the other months)
- standard deviation σ of the normal distribution relating demands and forecasts: $\text{Demand}(t) = N(Forecast(t), \sigma)$, where t is an elementary period of simulation. The different values of σ are : $\sigma = 0$, $\sigma = 10000$ $\sigma = 50000$, $\sigma = 100000$, $\sigma = 250000$.

The probability indexes of the market demand evolution scenarios are given in the following table. These indexes are based on the probability assessment scale given in Table 1.

Table 3 Scenarios probability indexes.

τ / σ	0	10000	50000	100000	250000
10%	1	2	3	4	3
50%	2	3	4	5	4
100%	1	2	3	4	3

The most likely scenario is the one corresponding to an average increase of demand associated with a large standard variation normal distribution. The more we go far from this scenario and the more the probability indexes decrease (i.e. the scenarios become unlikely).

Finally, the simulations were run on a six hundred-period (week) horizon.

7. RESULTS AND MANAGERIAL INSIGHTS

Due to the high combinatorial of experiments, only a summary of risk analysis resulting from the experimental data processing is presented (see Figure 4. to 7.). The method for compiling results is shown for the Figure 4. For the other curves (Figure 5. to 7.) , the method remains the same.

7.1 Without capacity constraints

We first consider the case when the capacity constraints are absent (infinite capacity i.e. capacity is considered to be always available in sufficient quantities):
Let's consider the stock cover = 0 and suppose that there is no forecast transmission. The criticalities of the different scenarios is given by the table 4.

By considering an objective function $f()$ as equal to the sum of the criticalities of the different market demand scenarios, we obtain the two surrounded points in the Figure 4.

Table 4 Cooperation policy with infinite capacity no forecast transmission and a stock cover =0.

Market scenarios		Probability indexes	Total Cost (c_1) & demand variability amplification (c_2)		Criticalities	
τ	σ	p_i	c_1	c_2	C_1	C_2
0,1	0	1	1171	5,0	1171	5
0,1	10000	2	1211	10,0	2422	20
0,1	50000	3	1823	9,7	5469	29
0,1	100000	4	2650	7,0	10600	28
0,1	250000	3	4411	4,3	13233	13
0,5	0	2	1278	2,0	2556	4
0,5	10000	3	1283	3,0	3849	9
0,5	50000	4	1944	6,3	7776	25
0,5	100000	5	2741	6,0	13705	30
0,5	250000	4	4449	4,3	17796	17
1	0	1	1732	2,0	1732	2
1	10000	2	1711	2,0	3422	4
1	50000	3	2205	3,7	6615	11
1	100000	4	2915	4,5	11660	18
1	250000	3	4565	4,0	13695	12
					$\sum$=115701	$\sum$=227

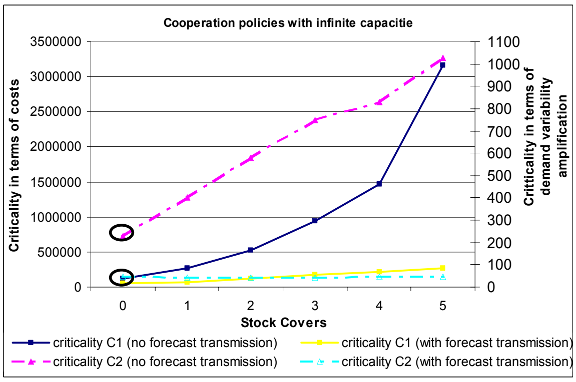

Fig. 4. Cooperation policies without capacity.

From figure 4, one should retain that:
• if there is no forecast transmission, risks of costs and of demand amplification increase with the stock cover.
• in the case of forecasts transmission, production costs and demand amplification are less sensible to the stock cover. Best results are obtained with no stock cover.

7.2 With capacity constraints

Now, the capacity constraints are considered and each actor defines his capacity in his S&OP process. Results for different capacity strategies (values of the capacity change acceptance ratio (p)) are given in figure 5, 6 and 7.

From these results, one can see that:

- here also, forecast transmission reduces drastically the risks of demand amplification whatever the capacity strategy.
- the stock cover influences the demand amplification only if no forecast are transmitted.
- with no forecast transmission and whatever the capacity strategy, a null stock cover does no more give the best cost: a small stock cover (stock cover =1 in Figure 5, Figure 6 and Figure 7) ensures at the same time low production costs and low demand amplification.
- For a stock cover greater than 1, the risk of cost increases linearly in function of the stock cover.
- analysing the impact of forecast transmission on the risks of the supply chain total costs, curves are significantly different only for a null stock cover. In this latter case, stock out are frequent and are much better managed in the case of forecast transmission.
- influence of the capacity strategy: for a stock cover greater than 1, the risk of the supply chain total cost is smaller for p=75% than for p=50% or 100%.

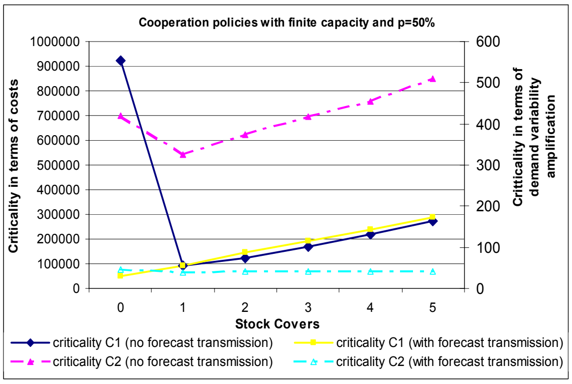

Fig. 5. Cooperation policies with finite capacity and p=50%.

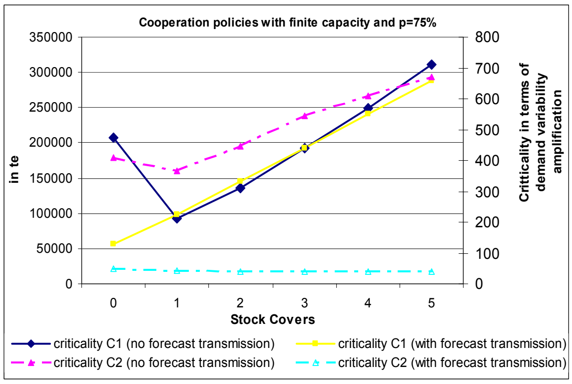

Fig. 6. Cooperation policies with finite capacity and p=75%.

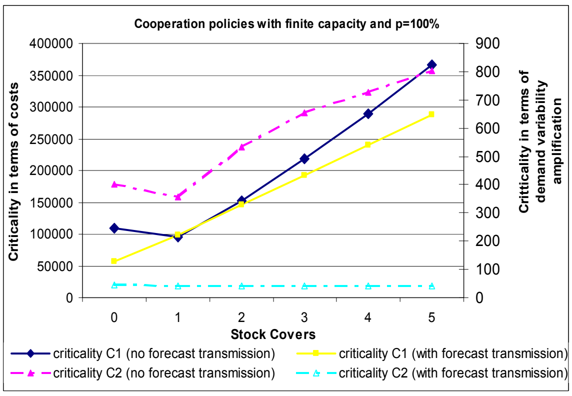

Fig. 7. Cooperation policies with finite capacity and p=100%.

In summary, we retain that, demand forecasts exchange reduces deeply the risks of demand amplification. But this is less effective considering the risks of the supply chain total cost: the reduction appears in a supply chain without

capacity constraints, but it is not significant if the capacity constraints must be managed.
Finally, for each information sharing strategy, simulations suggest values for the capacity change acceptance ratio (p) and for the stock cover (S).

8. CONCLUSION

We introduced in this paper some cooperation policies which highlight three cooperation dimensions: capacity planning, stock adjustment and information sharing. These cooperation policies were evaluated using a risk analysis approach which is supported by a discrete-event simulation tool developed specifically to implement such approach. A multi-stage telecom supply chain was used for the experimental validation.
This policies evaluation allowed us to understand the positive and negative influences of stock covers and information sharing on capacity planning.
Future research will keep the three cooperation dimensions presented in the paper but will concentrate on the enrichment of the information sharing dimension through the analysis of the implications of adding other exchanged information such as: the state of inventories of an actor to his supplier and the final demand of the market and its evolution. Moreover, cooperation methodology, based for example on an educational approach, is under study to initiate the discussion between decision-makers involved in setting up some of the retained cooperation policies.

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