A quantitative assessment of the collaborative production planning benefits in the automotive supply chain

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Abstract: The Italian automotive industry has a complex, articulated supply chain that splits in two different branches: the original equipment manufacturing (OEM, so new products) and the independent aftermarket (IAM, where spare parts are traded). The complexity of the relationships among the different actors, the high product variety with shortened life-cycles and the increased competition pushed companies to look for new, innovative solutions that allow them to survive in such competitive environment. The supply chain management practice focuses on the implementation of solutions allowing firms to face the increasing complexity of the current industrial scenario. In this context, collaborative practices can help enterprises to reduce the main logistics costs. The main objective of the work is to develop a quantitative model aimed at assessing the economic benefits stemming from the implementation of the collaborative production planning process in the automotive industry. Through case studies, a quantitative model that considers three actors in the automotive supply chain of new products is developed. Two scenarios are analysed: the AS-IS case, in which companies issue orders, and the TO-BE case, in which they exchange their production plans. The results show that the collaborative production planning reduces the overall level of inventories as well as the probability of stock-out (and the related costs) and the administrative costs, thanks to a lower number of exchanged documents; differently, it does not impact the handling costs, and it could lead to an increase in the transportation costs.

Keywords: eSupply Chain, Production Planning, Collaboration, Automotive Supply Chain.

1. Introduction

The Italian automotive industry has a complex, articulated supply chain that splits in two different branches: that of Original Equipment Manufacturing (OEM, so new products) and the independent aftermarket (IAM, where spare parts are traded). The complexity of the relationships among the different actors, the high product variety with shortened life-cycles and the increased competition pushed companies to look for new, innovative solutions that allow them to survive in such competitive environment. As a response, the concept of *Supply Chain Management (SCM)* tried to answer these challenges by encompassing the planning and management of all the activities: from sourcing to procurement, including logistics management, it stresses the fundamental role of collaboration and coordination with all the channel partners, within and across companies (Mentzer et al., 2001).

The two main SCM solutions that emerged, in order to support the firms of the automotive industry (and not only) are the exploitation of electronic and internet technologies, and the integration with other players through collaborative processes (Bakker et al., 2008). Therefore, we can talk about *electronic Supply Chain Management* (eSCM). The former solution, that exploits technologies such as EDI (and its evolutions i.e. Web-EDI and Internet-EDI) or Extranet portals, not only has a strong impact on the companies' cost structure by targeting wastes and boosting the overall efficiency; it also helps the different players to run their businesses across their firms' boundaries. The latter, indeed, stresses the importance of integrate each actor's activities with those of the players it deals with. In an industry where the final product has an incredibly high value and the actors manage wide, extended networks of relationships, it is fundamental to forecast the future trends, reducing as much as possible the variability and uncertainty that propagate along the supply chain (Sillekens et al., 2011). Therefore, the propose of the present paper is to provide a quantitative model aimed at assessing the economic benefits stemming from the implementation of the collaborative production planning process in the automotive industry.

The paper is organised as follows: Section 2 presents evidence from the literature review, Section 3 defines the research questions and adopted methodology, Section 4 introduces the model, and Section 5 summarizes the contribution and limitations of the model which can be addressed through future works.

2. Literature Review

The literature review on e-collaboration shows that the development of ICT has transformed traditional supply chains in advanced eSupply Chains and that their evolution coincides with the evolution of e-collaboration. Summarizing, e-collaboration evolved from the sharing of operational information to strategic one (Wang, 2006).

Focusing on the automotive industry, the literature has been analysed in two different sections:

(i) The role that technology plays in the adoption of collaborative processes;

(ii) The type of collaborative processes.

2.1 Role of technology in the adoption of collaborative processes

It has been highlighted how the use of a technology contributes positively to the adoption of collaborative processes. The topic has been studied considering different geographical boundaries: Reekers and Smithson (1996) studied the European automotive industry, focusing in particular on UK and Germany, which from the 80s' faced a fierce competition from Japanese and Korean car manufacturers that led to the increase of collaboration with preferred suppliers. Sanchez and Perez (2003) focused instead on the Spanish automotive industry. Their study investigated the hypothesis for which EDI is related to the co-ordination in the supply chain: their result shows that there is a positive correlation between the two factors. Wiengarten et al. (2013) discussed the German automotive industry, and Bensaou (1997) compared results from US and Japan automotive industry.

Moreover, although the relationship that has been taken into account is always the one between car manufacturers and their suppliers, different perspectives have been considered: the one of first and second tier suppliers (Sanchez and Perez, 2003; Wiengarten et al., 2013) and multiple perspectives from both suppliers and manufacturers (Reekers and Smithson, 1996).

2.2 Type of collaborative processes

The papers have also been analysed according to the collaborative process addressed. It has been found that only few papers address both the technology and the process (Adebanjo and Laosirihongthong, 2014); in most of them the focus is exclusively on the process and not on the technology enabling, even if in some cases it is mentioned.

Thus, the contributions have been analysed according to the process they describe, that are: Information Sharing, Vendor Managed Inventory (VMI), Collaborative Production Planning and Collaborative Planning, Forecasting and Replenishment (CPFR). No contribution has been found for the Efficient Customer Response (ECR) and the Collaborative Replenishment Planning (CRP).

Adebanjoa and Laosirihongthong (2014) addressed the topic of VMI with the aim of understanding its enabling factors, the outcomes and barriers to its implementation in the Thailand automotive supply chain, pointing out the fact that web-based order processing system is a pillar of the VMI itself. Nagarajan et al. (2012) studied, through a case study, a model of VMI for an automotive company and highlight the critical flaws in the system. The paper ends with an implementation model for VMI.

Although CPFR is not widespread in the automotive industry (Stone et al., 2008), some contributions focus on it. Danese et al. (2004) provided a theoretical framework that aims at explaining the relationship between coordination mechanisms and the characteristics of interdependence among the actors involved in CPFR; the model is based on a deep analysis of the activities of the process and on the results of a case study in the automotive industry. Panahifar et al. (2015) developed an analytical model to address the CPFR enablers, such as innovation capability, cultural fit or EDI, and highlight the need for decision makers to be aware of them before the implementation of the process. The model is based on a hybrid approach that combines fuzzy extended analytical and interpretive structural modelling. Liu and Sun (2012) described information sharing in the CPFR process; the paper is based on the case study of inbound logistics of an automotive manufacturer, that share data through the Internet of Things. The analysis of the information shared between customers, auto dealers, auto manufacturers and suppliers are made according to the phases of the process, that are strategy and planning, demand and supply management, execution and analysis.

Demiray et al. (2017) focused instead on developing an implementation roadmap for CPFR adoption. Moreover, they tested the roadmap on a real case study between a first-tier supplier and its aftermarket customers and they demonstrated, through a KPIs dashboard, the benefits stemming from the use of such tool.

Another field of research is about collaborative planning. Stadtler and Kilger (2002) made a description of the collaborative planning process using the example of a manufacturer of headlight modules for the automotive industry and considering the following phases of the process: local domain planning, plan exchange, negotiation and exception handling, execution and performance measurement.

The information sharing process is a building block of any more advanced collaborative process, from VMI to collaborative planning to CPFR. However, in practice it is a widespread stand-alone process and many contributions address it, taking different perspectives. For instance, Ho et al. (2007) developed a study for investigating the combined effect of information sharing and coordination mechanism for reducing the uncertainty in an automotive supply network; they found out that the combination of inter-organizational process redesign and information sharing influences significantly supply chain performances. Also, Arshinder and Deshmukh (2007) focused on the relationship between information sharing and supply chain coordination, by developing a model to measure the extent of supply chain coordination in an organization, in which information sharing is one of the coordination mechanisms considered, together with contracts, IT and collaborative initiatives. The model is validated on the case study of an automotive parts manufacturer.

Another field of literature discussed about quality of information. For instance, Baihaqui and Sohal (2013) found that it is positively related with the intensity of information sharing. Wiengarten et al. (2010) expanded the literature on information sharing by studying the impact of information quality on collaborative process. Through a case study developed in the German automotive industry, they found out that timeliness, accuracy, relevance and value-added of the exchanged information has a very significant impact on the performance of the collaborative process. Similarly, Myrelid (2017) explored the effect of information quality deficiencies on the supplier's production scheduling process, in the Swedish automotive industry. The study revealed that receiving frequency, planning period, frozen period and demand variation of the exchange of delivery schedules affect credibility, timeliness, completeness, reliability and conciseness of the information exchanged. Information distortion has been studied by Niranjan et al. (2010) that, building on the issue of Bullwhip effect, firstly introduced by Lee et al. (1997), proved that the degree of over-ordering is a good indicator of information distortion, for an automotive supply chain made by three echelons, OEM, first, and second tier suppliers.

Stone et al. (2008) focused on the reason why collaborative initiatives fail, by studying four real cases of collaborative planning implementation. The results highlighted that the barriers to implementation are structural, cultural, managerial, user and technical needs and could be related to the barrier of the implementation of a technology, discussed previously.

From these evidences, it does not exist a broad, wide, literature review on the theme of eSCM in the automotive industry. Wang (2006) made an attempt to describe the different methods of eSC-collaboration, but the automotive sector is addressed in a marginal way. Second, VMI or CRP are the solutions mainly addressed, but the description often stops at the concept and who are the actors that communicate, or what kind of information those actors exchange. Strictly related to the former gap, no-one attempted to estimate in a quantitative manner (time, inventory, and other resources saved) the benefits of implementing a specific technology in a determined process. A clear example of what should be done, is provided by Perego and Salgaro (2010), where they estimated the benefits deriving from implementing the EDI in the order-to-pay cycle in the home appliances industry; nevertheless, it does not exist a similar result for the automotive industry.

3. Objectives and Methodology

Given the identified gaps, this paper attempts to contribute to the extant literature by proposing a model, which aims to assess the benefits stemming from an eSupply Chain Collaboration in the automotive industry. From a study of the eInvoicing & eCommerce B2b Observatory (2018), the most widespread Collaborative practice implemented in the automotive industry in Italy is the Collaborative Production Planning. Thus, the model will concern this specific project.

The research questions identified are the following:

- RQ1 – What are the factors affected by the Collaborative Production Planning process?
- RQ2 – What are the benefits stemming from the Collaborative Production Planning process?

We aim at quantifying the benefits of the Collaborative Production Planning process in a supply chain of at least three actors (all the articles consider a two actors' relationship, without estimating the benefits in quantitative terms) and the distribution among them. In addition to that we have created a model extendible to more actors in the supply chain.

The methodology followed is constituted by the following steps:

1) Literature analysis: the literature analysis had the primary purpose of understanding the research context and identify the gaps to target. At the end of the literature analysis, we had in mind which were the gaps to focus on (those of the research questions) and how to address them.

2) Interviews (1st round) and research on secondary sources: we made a first round of interviews with the IT managers of 23 companies with the purpose of understanding a set of relevant information: some general information about the company, (e.g. position in the supply chain); then we focused on the Italian supply chain description and the dynamics among the actors; finally, we entered in the detail of the digitalization and eSC collaboration projects accomplished. Only 11 of them had already implemented the Collaborative Production Planning project (see the Appendix A).

3) Interviews (2nd round): through a series of 11 interviews, this time carried out to the logistics manager of the companies and supported by a questionnaire, we managed to understand which are the traditional activities of the collaborative planning process, how they are impacted by the process implementation and how they affect the costs.

4) Model development: we realised a mathematical, parametric model on an excel spread sheet, where two scenarios are illustrated: the AS-IS case, where the companies exchange orders, and the TO-BE case, where they exchange the production plans.

5) Model application and validation: once completed, we tested the model by inserting the data of 3 companies of the Italian supply chain (a 2nd tier supplier, a 1st tier supplier and a car maker) and we compared the obtained results with those they measured before. The correspondence confirmed the validity of our work and the possibility to apply it to the other actors of the supply chain.

6) Sensitivity analysis: we carried on a sensitivity analysis by changing single values of the variables in our model (e.g. the yearly demand, the number of withdrawals in the time interval between two plans or again the frequency of plans updating).

4. The Model

We decided to proceed in our model definition, by following an Activities Based Cost (ABC) logic, with the purpose of defining the traditional activities carried on by two actors while exchanging orders, how they varies by implementing the collaborative process of exchanging production plans, and the relative impact on the costs drivers represented by specific variables.

In order to accomplish our objective, the first step was to understand first which are the current activities (base case AS-IS) that companies carry on, in which there is no collaboration between actors (for a synopsis of the process see the Appendix B) and second how do they change when they implement the collaborative process (the TO-BE situation), in which the car maker and the first-tier supplier send their production plans to their suppliers, respectively the first-tier supplier and the second-tier supplier (see the Appendix C).

The main difference between the two processes consists in the order exchange, that is substituted by the withdrawal schedule embedded in the production plan. To each activity, we associated a cost, ended up with five main costs considered: inventory carrying, handling, stock out, transportation and administrative.

Subsequently, we parameterised each cost with a specific, associated variable, in order to compose the different cost functions. Following that, we tried to understand how the traditional activities changed once implemented the collaborative process (so called TO-BE situation) and, similarly to what done before, associate determined variables to the (new) cost drivers, generating once again the functions representing the main logistics’ costs.

The initial structure of our model has been built thanks to a strong cooperation with the companies of the automotive industry, that told us which drivers and functions were correctly applied (we initially took them from the literature) and which, instead, were calculated differently in their working environment.

The model has been developed starting from some basilar hypothesis that have been enlisted and explained below:

1) The supply chain considered consists of three actors: a 2nd tier supplier (F2), a 1st tier supplier (F1) and a car maker, or vendor (V).
2) The warehouses are managed according to the Periodic Review Model and the inventory level are continuously updated.
3) During the calculation of the inventories in the lead time, the pace whereby inventories are consumed is supposed to be not constant.
4) The company keeps a determined level of inventories as *safety stocks*, in order to face the real variability of consumption of the inventories and of the delivery lead time.
5) The daily demand during the time interval follows a normal distribution, with average and standard deviation so that $D = N(d; \sigma_D^2)$
6) The duration of the lead time follows a normal distribution $N(LT, \sigma_{LT}^2)$
7) The transportation cost is entirely sustained by the client in both cases, AS-IS and TO-BE; the reason why we allocated everything to the actor downstream is because in the TO-BE case it emerged (according to the interviews) that is the customer that pays when withdraw the inventories required.
8) The costs for the emission of a single order depends on the number of lines in each order that determine the number of documents that we have to send; moreover, it depends on the specific technology used to send the documents. The total administrative costs depend on the number of documents exchanged and on the technology used (e.g. EDI, fax, mail).
9) It is not possible to plan the stock-out. This would be possible in a system with no safety stock because of the low variability of the demand.
10) We did not consider speculative sales.
11) Only the car maker and the 1st tier supplier send their production plans upstream, while the 2nd tier supplier does not.
12) We assumed that the average level of inventories in input of an actor is equal to the average level of raw materials/components/finished products of the upstream actor; therefore, the benefit perceived in terms of reductions, is the same for both actors.
13) There are not third parts logistics’ provider (3PL) and the productive plant coincides with the warehouse of each actor.
14) The value of k in the safety stocks calculation, is kept constant in both cases AS-IS and TO-BE.
15) The interval between two production plans exchanged must be lower or equal to the time interval between two orders exchanged in the AS-IS scenario ($P^* \leq T$).
16) The frozen period, that is the closer period in the production plan and should almost express a fixed demand, is just a commercial agreement between two actors. In the frozen period (and in the production plan in general) the quantities vary according to the number of times the downstream actor updates its plans.
17) In the TO-BE scenario, the number of inventories is strictly related to the number of withdrawals done by the downstream actor, with a possible impact also on the transportation cost.
18) The transportation cost does not depend on the distance between two actors, but an average is considered.

The dynamics of the models are described in Table 1, that shows, for each cost element, what are the impact and the drivers of the implementation of Collaborative Production Planning.

Table 1: Elements impacted by the adoption of Collaborative Production Planning

	SUPPLIER		CUSTOMER	
Element	Impact	Driver	Impact	Driver
Cycle Stock	*Reduction*	Withdraw al frequency	*Reduction*	Withdraw al frequency
Safety Stock	*Reduction*	Lower demand variability (σ_D^2)	*Reduction*	Lower delivery lead time variability (σ_{LT}^2)
Service Level	*Increase*	Lower variability and uncertaint	*Increase*	Lower variability and uncertaint y of the

		y of the demand		delivery lead time
Administrative Costs	*Reduction*	Reduced quantity of documents to manage	*Reduction*	Aggregation of orders in a single production plan
Transportation Cost	*Reduction /Equal*	It is the client that organizes the transportation for withdrawal	*Increase/ Equal*	Depends on the trade-off between saturation and withdrawals frequency
Handling and Picking Cost	*Equal*	Annual flow	*Equal*	Annual flow
Stock Out Cost	*Reduction*	Lower stock-out probability	-	-

The theoretical model has been applied and validated by inserting the data and parameters (e.g. time interval between two orders) of three firms belonging to the supply chain of tires: a 2nd tier supplier, a 1st tier supplier, and a car maker. The car maker exchanges plan with the first-tier supplier, the first-tier with the second-tier supplier, while the second-tier supplier does not exchange with the third-tier, since their relationship – with unbalanced bargaining power – does not make it possible. The data shared during the interviews has been using in the formula showed in the Appendix D (referring to the five costs considered). Since the range of the items is a key driver in the assessment of the costs, the products have been clustered into three classes for the vendor (Basic, Premium, Deluxe), four for the 1st tier supplier (Basic, Premium, Deluxe and Worked Rubber), and two for the 2nd tier supplier (Worked Rubber and Rubber). For the data of the base case see the Appendix E.

The results stemming from the model (i.e. the evaluation of the achievable benefits obtainable from the implementation of the collaborative production planning process) are reported in the Table 2.

Table 2: Numerical benefits

	Inventory Carrying Cost	Handling Cost	Stock-Out Cost	Administrative Cost	Transportation Cost	Total
Car maker	71%	0%	0	50%	0%	1%
1st tier supplier	70%	0%	92%	50%	0%	44%
2nd tier supplier	38%	0%	17%	50%	0%	17%
Supply Chain	54%	0%	90%	50%	0%	**15%**

The results obtainable by implementing the collaborative production planning process show benefits spread in a not uniform measure on the different logistics' costs. The inventories can be reduced up to seventy percent, thanks to a higher withdrawal frequency; the administrative costs (assimilated to the cost of exchanging documents) are significantly impacted too with a reduction of almost 50%, thanks to the possibility to aggregate the various documents sent upstream/managed downstream; the handling costs should decrease, but their proportionality to the yearly flow and to the infrastructures does not translate in a benefit; the stock out costs – that in the upstream automotive industry has a limited impact and a specific meaning compared to other sectors – decreases up to 92% but their impact is low on the total costs, while the transportation cost, the last element to consider, could also rise significantly, pushing the players to analyse the trade-off between transportation and inventory carrying cost. Considering the supply chain made by the three actors, the total benefit is a reduction of 15% of the costs considered.

After computing the benefits arising from our model, the validation was accomplished by taking into account 3 companies (a 1st tier supplier, a 2nd tier supplier and a vendor) – not yet interviewed – that had already implemented the Collaborative Production Planning project. These enterprises shared the savings they measured internally from the usage of such solution. The output (see the Appendix F) is almost a complete match compared with the results of our model, that certifies the accuracy and precision of our work. Thus, we have the certainty of a model that not only is accurate and complete (it includes all the main cost items), but also reliable for the management and companies willing to have an insight on the improvement reachable by cooperating with their upstream and downstream partners.

4.1 The sensitivity analysis

Once obtained the benefits implementing the Collaboration Production Planning, the sensitivity analysis was performed. Its purpose was to identify the most relevant factors impacting the benefits. The sensitivity analysis was focused on four key parameters:

i) ED: volumes of demand;

ii) P*: the time interval between the exchange of two production plans;

iii) f_{agg}: the updating frequency of the production plan;

iv) number of collections during P*.

The first variable is a data of the AS-IS situation, thus it will show how the benefits change by changing the starting scenario. The last three variables are, instead, related to the TO-BE situation and will show which one is more impacting on the achievable benefits.

Volumes. The impact of volumes on the model has been tested with four different scenarios. Starting from a basic case, in which the demand is 100%, we changed the demand volumes to 25%, 50% an 125%.

Results show that the benefits are proportional to the volumes. Indeed, by changing the volumes, the percentage of benefits is unchanged. The only difference is found in the transportation cost: in case of low volumes, there is a worsening of the transportation cost. This is due to the fact that, if the volumes exchanged are low, the fact of collecting goods with high frequency make it possible to send trucks that are unsaturated and the threshold of the best trade-off between the inventory carrying cost and the transportation cost is overcome. However, this situation is quite common in the automotive industry.

The time interval between the exchange of two production plans. The impact of the change in the time interval between two orders has been tested on three different scenarios, in which P* has been set at 5, 10 and 20 days. Same values have been applied to the exchange between the vendor and the first-tier supplier and the first-tier supplier and the second-tier supplier. In order not to consider the impact of the frequency of collections, the number of collections during the time P* has been changed such that there is one collection every 5 days. Moreover, in order to consider different improvements in the SDE, LT and σ_{LT}, the frequency of update has been set at 1 day, meaning that the production plans are updated every day. Overall, the frequency of production plans exchange impacts marginally: indeed, the benefits come from the reduction of σ_D, that becomes SDE, the reduction of LT and of σ_{LT}. These factors impact only on the safety stock with a low variation, due to the situation considered – that is, the worse scenario – and they are then multiplied, summed and square rooted. The change is therefore only on the inventory carrying costs and of less than 1%.

The updating frequency of the production plan. For the updating frequency three scenarios have been tested. The values of f_{agg} are 1 day, 3 days and 5 days, on a P* of 5 days. As for the P* scenarios, the results show a small improvement in the value of safety stock, that also in this case is lower than 1% for each one of the three actors.

Number of collections during the time interval. The last set of scenarios has been conducted by changing the frequency of collection, keeping constant the other parameters. The scenarios consider the same number of collections per week per each actor, starting from once every two weeks, to once every two days, to once a day. The results show huge improvements in costs: the inventory costs are reduced thanks to the reduction of cycle stock. Indeed, by shortening the time between two collections, the T* is reduced and it impacts directly on the cycle stock. The increase is not linear, as the marginal increase of benefits decreases as α increases. By going from one collection every two weeks (α=1) to a collection every two days (α=5), the increase in inventory carrying costs is 57% for V, 59% for F1 and 10% for F2; while by going from a collection every two days (α=5) to once a day (α=10) the benefit respectively increases by 8%, 7% and 2%.

Overall, it is possible to conclude that the variable that impacts the most on the benefits realisation is the number of collections during the time period: the higher the collection frequency, the lower the amount of cycle stock and therefore their cost.

The results are showed in the Appendix G, in which the percentage improvement is shown, shifting to different scenario in which the variable in the first column is changed. Thanks to the sensitivity analysis, players willing to apply the model to their working reality will have the possibility to act on a single, specific variable or more than one simultaneously, according to thei necessity, cost structures and policies.

5. Conclusion

The model presented in this paper aim to fill the gap still present in the extant literature. Then, it represents a useful guide to boost the adoption of the Collaborative Production Planning solution for the firms of the automotive industry, highlighting the benefits stemming from its implementation.

The model has some limitations. First of all, we considered just the logistics costs: indeed, the collaboration has an impact on the production scheduling and, therefore, on the costs related to the lot size, the urgent scheduling and so on. The second limitation is due to the service level, that has been considered constant in the computation of safety stock from the AS-IS to the TO-BE situation. Moreover, the model does not consider the fact that a higher service level would attract more customers and therefore allows an increase of the turnover in the medium-long term. Another limitation is due to the proxy made for the exchange of documents in the TO-BE situation: indeed, we have considered an aggregated data of documents instead of considering the number exchanged for each type of document. Moreover, the model is based on the hypothesis that the inventory in the AS-IS situation is managed according to a period review logic: therefore, it limits the application to those firms that use a period review logic. However, we are confident that this is a characteristic of the part of the automotive supply chain considered.

Since the model has been tested specifically for the tires supply chain, it would be interesting to add other actors in the supply chain (e.g.: the authorised dealers downstream and the suppliers of raw material upstream), and looking at how benefits spread all along the end-to-end supply chain. It would be also interesting to expand the model to an international supply chain, developing it with the foreign players that interact with Italian companies. This would allow to consider environmental and geographical factors, such as the distance between two players, to see how they affect the risk related to the supply chain. Finally, a further development of the model could be done by considering the effect of the exchange of productions plans on production costs: according to the interviews done, indeed, the visibility on customers' production plans allows to eliminate the urgent production lots, that must be activated for instance to cover a stock out.

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Appendix A. INTERVIEWS

	Company	Role in the supply chain	2nd round
1	Company 1	Car maker	interviewed
2	Company 2	2nd tier supplier	interviewed
3	Company 3	Retailer	not interviewed
4	Company 4	1st tier supplier	not interviewed
5	Company 5	1st tier supplier	interviewed
6	Company 6	Wholesaler	not interviewed
7	Company 7	1st tier supplier	interviewed
8	Company 8	Car maker	interviewed
9	Company 9	1st tier supplier	not interviewed
10	Company 10	Retailer	not interviewed
11	Company 11	Car maker	interviewed
12	Company 12	Car maker	not interviewed
13	Company 13	1st tier supplier	not interviewed
14	Company 14	1st tier supplier	interviewed
15	Company 15	Authorised Dealer	not interviewed
16	Company 16	Wholesaler	not interviewed
17	Company 17	1st tier supplier	interviewed
18	Company 18	Car maker	not interviewed
19	Company 19	1st tier supplier	interviewed
20	Company 20	2nd tier supplier	interviewed
21	Company 21	Wholesaler	not interviewed
22	Company 22	Car maker	interviewed
23	Company 23	Service provider	not interviewed

Appendix B. ACTIVITIES OF THE AS-IS SITUATION

2nd tier supplier	1st tier supplier	Vendor/Car Maker
Elaboration of historical data	Elaboration of historical data	
Demand forecast	Demand forecast	
Elaboration of the production plan	Elaboration of the production plan	
Production	Order emission to F2 (AC)	
Reception of the order from F1 (AC)		
Warehouse material check		
Satisfied order vs Stock-Out (SOC)		
Picking		
Transport/delivery		
	Reception of the goods ordered (TC)	
	Inventory stock (ICC)	
	Production (MTO vs MTS) (Production cost; HC)	
	Stock of components (ICC; HC)	
		Order emission (AC)
	Reception of the order from V (AC)	
	Warehouse material check	
	Satisfied order vs Stock-Out (SOC)	
	Picking	
	Transport/delivery	
		Reception of the goods ordered (TC)
		Inventory stock (components and finished products) (ICC)

Appendix C. ACTIVITIES OF THE TO-BE SITUATION

2nd tier supplier	1st tier supplier	Vendor/Car Maker
		Production plan elaboration
		Production plan sharing with F1 and production plan issue (AC)
	Production plan reception from V (AC)	
	Elaboration of the production plan	
	Production plan sharing with F2 and production plan issue (AC)	
Reception of production plan from F1		
Elaboration of the production plan		
Production		
Satisfied order vs Stock-Out (SOC)		
Picking (HC)		
Transport/Delivery		
	Raw materials receipt (TC)	
	Stock of raw materials (ICC)	
	Production (MTO vs MTS) (Production cost)	
	Components stock (ICC; HC).	
	Picking	
	Transport/Delivery (TC)	
		Goods receipt
		Stock of components/finished products (ICC; HC)

Appendix D. NOTATIONS AND FORMULAS USED FOR THE MODEL

Notation	
ICC	Inventory Carrying Cost
phc	percentage of holding costs
CS	Cycle Stock
SS	Safety Stock
HC	Handling Cost
hc	percentage of handling costs
D	demand during the time T
v_i	value of the component i
SOC	Stock Out Cost
pi	punctuality index
pls	probability of lost sale
m	margin
AC	Administrative Cost
doc	document
c_D	cost of exchanging one document
TC	Transportation Cost
t	number of trips
c_T	cost of a trip

Actor	Formula
Inventory Carrying cost	
V	$ICC_V = \sum_{i=Basic,Premium,Deluxe} (phc_i * (CS_i + SS_i) * v_i)$
F1	$ICC_{F1} = \sum_{i=Basic,Premium,Deluxe,\ Worked\ Rubber} (phc_i * (CS_i + SS_i) * v_i)$
F2	$ICC_{F2} = \sum_{i=Worked\ Rubber,Rubber} (phc_i * (CS_i + SS_i) * v_i)$
SC	$ICC_{SC} = \sum_{j=V,F1,F2} ICC_j$
Handling cost	
V	$HC_V = hc * \sum_{i=Basic,Premium,Deluxe} D_i * v_i$
F1	$HC_{F1} = hc * \sum_{i=Basic,Premium,Deluxe,Worked\ rubber} D_i * v_i$
F2	$HC_{F2} = hc * \sum_{i=Worked\ Rubber,Rubber} D_i * v_i$
SC	$HC_{SC} = \sum_{j=V,F1,F2} HC_j$
Stock-out cost	
V	$SOC_V = (1 - pi_V) * pls_V * m_V * \sum_{i=Basic,Premium,Deluxe} D_i * v_i$
F1	$SOC_{F1} = (1 - pi_{F1}) * pls_{F1} * m_{F1} * \sum_{i=Basic,Premium,Deluxe} D_i * v_i$
F2	$SOC_{F2} = (1 - pi_{F2}) * pls_{F2} * m_{F2} * D_{F2} * v_{F2}$
SC	$SOC_{sc} = \sum_{j=V,F1,F2} SOC_j$
Administrative cost	
V	$AC_V = doc_{V-F1} * c_D$
F1	$AC_{F1} = c_D * \sum_{l=V-F1,F1-F2} doc_l$
F2	$AC_{F2} = doc_{F1-F2} * c_D$
SC	$AC_{SC} = \sum_{j=V,F1,F2} AC_j$
Transportation cost	
V	$TC_V = t_{F1-V} * c_{T,F1-V}$
F1	$TC_{F1} = t_{F2-F1} * c_{T,F2-F1}$
F2	$TC_{F2} = t_{F3-F2} * c_{T,F3-F2}$
SC	$TC_{SC} = \sum_{j=V,F1,F2} TC_j$

Appendix E. DATA OF THE BASE CASE

	Value		LT		σ_{LT}		phc		T	
Basic	50	€/tyre	20	Days	5	Days	10	%	10	Days
Premium	75	€/tyre	30	Days	6	Days	20	%	15	Days
Deluxe	100	€/tyre	40	days	7	days	30	%	20	days

	Value		LT		σ_{LT}		phc		T	
Worked rubber	3	€/kg	80	Days	10	Days	10	%	10	Days

	Value		LT		σ_{LT}		phc		T	
Rubber	2,5	€/tyre	40	Days	10	Days	10	%	60	Days

Variable	Value	Unit
P_v* (F1-V)	5	days
f_{agg} (v) (F1-V)	5	days
α (F1-V)	3	collections

Variable	Value	Unit
P_v* (F1-F2)	5	days
f_{agg} (v) (F1-F2)	5	days
α (F1-F2)	1	collections

Number of collections during the time P* (α)	[1%;9%]	[6%;47%]	[6%;48%]	Reduction of Cycle Stock (one of the principal costs)

Appendix F. OUTPUT OF VALIDATION

	Inventory Carrying Cost	Handling Cost	Stock-Out Cost	Administrative Cost	Transportation Cost	Total
Car maker	69%	0%	0	50%	0%	1%
1st tier supplier	70%	0%	92%	50%	0%	44%
2nd tier supplier	38%	0%	18%	50%	0%	17%
Supply Chain	54%	0%	90%	50%	0%	**15%**

Appendix G. SENSITIVITY ANALYSIS

Variable	2nd tier supplier	1st tier supplier	Car maker	Impacts
Volume	< 1%	< 1%	< 1%	Benefits in costs are proportional to volumes
Time interval between the exchange of two production plans (P*)	< 1%	< 1%	< 1%	Reduction of σ_D, that becomes SDE, reduction of LT and of σ_{LT} - changes are marginal since they impact only on the Safety Stock
Updating frequency of the production plans (f_{agg})	< 1%	< 1%	< 1%	Reduction of σ_D, that becomes SDE, reduction of LT and of σ_{LT} - changes are marginal since they impact only on the Safety Stock