D24.1

Business and Security Requirements

Project number:	609611
Project acronym:	PRACTICE
Project title:	PRACTICE: Privacy-Preserving Computation in the Cloud
Start date of the project:	1st November, 2013
Duration:	36 months
Programme:	FP7/2007-2013

Deliverable type:	Report
Deliverable reference number:	ICT-609611 / D24.1/ 0.1
Activity and Work package contributing to the deliverable:	Activity 2 / WP 24.1
Due date:	Apr 2014 – M06
Actual submission date:	5th May 2014

Responsible organisation:	DTA
Editor:	Antonio Zilli
Dissemination level:	Public
Revision:	0.1

Abstract:	Supply chain processes optimization requires collaborative planning systems to be used by many partners. Cloud IT systems could enable collaboration in wide and global supply chains (i.e. aerospace and consumer goods). By analysing current planning procedures, innovative functionalities and the related security requirements for a collaborative cloud planning system are proposed.
Keywords:	Aerofleet management process, consumer goods distribution planning, cloud collaborative planning system, collaborative forecasting, vendor managed inventory, secure multiparty computation.

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Disclaimer

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 609611.

Executive Summary

The growing of the economic value of the aero-engine maintenance business sector is pushing for more cooperation among the supply chain partners (engine owners, service provider, components suppliers). In example, the overhauling planning process shows high opportunities for optimization thus reducing both total inventory costs and turn-around time. The actors involved in the service send products and data to their direct business partner (client, supplier) generally in a way and time they cannot optimize the process at supply chain level, then reducing global capabilities to react to unexpected, then unplanned, events.

Theoretical collaborative models are more and more effective in optimizing operations at supply chain level, in particular two models are very promising: collaborative forecasting and vendor managed inventory. The first model is particularly effective when the supply chain is characterized by many sources of information, the second one instead is well suited when the supplier can develop deep knowledge on the market trends of its customer(s).

However, in spite of the benefits these models promise, they are not so diffusely applied due to the fact that the disclosure of the data required in the computation adversely affects the business capabilities of the owner: they convey information on current and future business conditions.

Cloud systems and Secure Multiparty Computation (SMC) are challenging such industrial requests: cloud systems provide scalable and cost effective computation resources, doesn't require high ICT expertise in users, and can reach, and involve, into the process also far and small actors; SMC shows powerful security performance that could convince owners of the most confidential data to apply trustfully such computation technology.

These technology innovations, namely cloud systems and SMC, can be used to develop a collaborative planning system aimed at optimizing overhauling process in a community of engine owners (airlines / air force), maintenance, repair and overhaul service providers, and part suppliers. By analysing the risks and impacts of data leakage and the expected process to be run, functional and security requirements are developed. The designed Cloud Collaborative Planning System, will enable these actors to rape the benefits of reducing costs involved in servicing aero-engines without threatening the confidentiality of their business and production data, with the results of making more competitive the supply chain applying such technological system.

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Chapter 1 Introduction

The supply chain covers all activities associated with the flow and transformation of goods and the related information from raw materials to final products provided to the end users. In other words, a supply chain can be defined as a network of suppliers, factories, distribution centres and retailers, that purchase raw materials, semi-finished products/components or services in order to transform them aiming to deliver a complete and valued product to the customer (Misra, Khan and Singh, 2010). Slack et al. (2001) argues that "Supply chain management is the management of interconnection of organizations which relate to each other through upstream and downstream linkages between the different processes that produce value in the form of products and services to the ultimate consumer". Supply Chain Management (SCM) is based on the existence of proactive relationships between buyers and suppliers and the integration across the whole supply chain.

In this scenario ICT plays a dominant role as a natural and necessary part of SCM, to ensure business relationships existence (Hsu and Wallace, 2007; Rai et al., 2006). A good strategy to manage integrated supply chain is to share information among supply partners, as the lack of knowledge sharing significantly affects overall performance (Armistead and Mapes, 1993; Bhaskaran, 1998). Researchers showed that a well-designed ICT solution for SCM has different benefits, such as faster new product design, improved coordination and purchasing, lead-times reduction, smaller batch sizes, reduced inventory levels, order fulfilment cycle reduction, better operations and performance (Hammer, 1990; Anand and Mendelson, Clark and Hammond, 1997; Lee and Whang, 2000; Li, 2000; Hult et al., 2004; Cai et al., 2006; Shah and Shin, 2007). Anyway partners are very reluctant to share information as they fear to lose competitive advantage in favour of other actors involved into the same industry. The result is that supply chain global performances are lower than the optimal ones.

In the following, the aeronautic and the consumer goods industries are presented. In particular, the engine Maintenance, Repair and Overhaul (MRO) business sector is mainly discussed as it is more and more relevant in the aeronautic industry and there are many opportunities to introduce innovative collaborative systems aimed at improving the quality of the service.

This business sector is characterized by a change in the contract type: it is moving from a 'time and material' contract toward a 'performance-based' one. In this new business scenario, all responsibilities, and the related risks, on the decision making process are in charge of the MRO service provider that is paid as much as high is efficiency the fleet. The most important metric to evaluate the performance of such relationship is the 'product reliability and availability': the product reliability is dependent on the quality of MRO service processes (remove, disassemble, clean, inspect, repair and test), the availability of the product is in part determined by the service lead time and in part by the planning capabilities of the MRO supply chain. So, the product availability metric can be improved if customers and suppliers of the MRO service provider collaborate to the planning process by providing their data, in example data about the fleet usage and inventory and production status.

Scientific literature is very concentrated in studying supply chain collaborative models in order to evaluate the global business performance that a supply chain can challenge with respect to the node industrial features. Production lead time, demand variability, purchasing order cost, forecast horizon among others are properties impacting on the most effective collaborative model. Two of the most applied models explored for application into MRO service sector are the collaborative forecasting and the vendor managed inventory. The first model is very promising when many private information sources are available in the supply chain, while the second is quite effective if the supply of products and the related inventory management is critical for an effective demand satisfying.

The availability of the mentioned individual data while enables new collaborative practices, introduces a lot of issues related to their confidentiality. The status of the fleet is the most important data for an airline (and much more for air force) since future performances can be inferred from them. Similarly, business relationships between MRO service provider and suppliers, OEMs or retailers, are strongly dependent on the capability to respect delivery plans. Similarly, in the consumer good industry demand forecast, orders and product distribution data are very sensitive data that flow in the supply chain to coordinate and align production inventories status and product shipment in the suppliers' sides.

A cloud planning system would provide general benefits because enable simple data availability, but increases the confidentiality threats coming from the service provider, that will have access to the computation system, and from the other process participants, that could access confidential data stored in that central system. Secure computation technology is expected to introduce a radical innovation in such systems since it is able to reduce (or cancel) risks related to loosing confidential data toward both service provider and other process participants: secure computation is computing of encrypted data.

As theoretical collaborative models and implementing strategies are proposed, the aeroengine MRO business industry and the related innovation needs for MRO service planning is presented. The functionalities proposed for a secure collaborative cloud planning system are proposed and, basing on them, the data required from each actor are identified. The identification of the data is mandatory for highlighting the risks run by system's users with respect to the different attack scenario (data leakage toward other user or toward external attackers) and to propose security requirements.

The objective of the report is to identify the main elements necessary for designing a secure collaborative planning system: the industrial features, the process description, some theoretical collaborative models that could be applied, the computation capabilities actually available, and, in the end, the functional and security requirements for a cloud collaborative planning system. The main features of the target industries, aeronautic and consumer good, will be introduced in the section 2. Specifically, the MRO business service challenges and the data flow in consumer good production and shipment are presented to highlight how improving collaboration at supply chain level can drive business performances. Two theoretical collaborative models, collaborative forecast and vendor managed inventory, will be presented in the section 3. These models are widely discussed in scientific literature and are positively applied in some supply chains to optimize the production and distribution of products in the supply chain nodes. The current practices of the aeronautic and consumer goods industries are presented in the second part of the section 3, the description is aimed at highlighting the distance between the industrial context from the theoretical models. This gap and a customization of the mathematical models will be analysed in next phase of the project.

The collaborative forecast and vendor managed inventory are based on the sharing of data and for this reason the probability to be applied are very low if not absent at all. The secure multiparty computation technology, whose security features are presented in the section 4, can be applied to reduce or cancel security threats. SMC can be implemented in different and the specific implementation is tailored on the algorithm to be computed and on the security level it has to present. Cloud environments can reduce the most negative aspects of such a technology: the high need of computation resource. In the section 5 the design of a collaborative supply planning system is introduced, in particular the functionalities and the benefits are discussed with respect to the potential industrial usage scenarios. These positive aspects are combined with the risks and threats of sharing confidential data that impose security requirements.

As the new collaborative processes, the supply planning models and the technology to be applied are identified, the next project activity will be to customized the mathematical model on the actual aeronautic and consumer goods industry and design the systems.

Chapter 2 Industry overview

2.1 Aerospace industry

The aerospace industry is dominated by US (Boeing, Lockheed-Martin, Northrop Grumman) and European companies (EADS[1] and BAE Systems) that participate in a dense network of relationships. A lot of actors (organizations) participating in this network collaborate and compete with other actors at the same time.

In this industry, a profound reorganisation of supply chain started since the 1980s, as changes in the product technology have modified the industry competitive factors and the leader firm's role. Today it is possible to observe important changes in three different levels (Esposito and Passaro, 2009):

1. at *intra-firm level*, large firms are reducing the direct manufacturing activities and reallocating the core competences and technologies to exploit higher value-added activities and services; this trend is increasing the criticality of the system of relationships among the business activities carried out in the aeronautic supply chain and is pushing toward higher level of coordination among customer and suppliers;
2. at *intra-industry level,* aeronautic firms that want to maintain their leadership are investing more and more in the equipment and avionics (that means comfort for passengers and flights control and security); the result is a different equilibrium among the different technological areas;
3. at *inter-industry level,* many large firms are investing in technological improvements, leveraging new information and communication technologies (ICTs), with result that industry boundaries are extending.

Overall, ICT-based and service-oriented business sector of the aeronautic industry is growing and growing.

2.1.1 Vertical and horizontal relationships

In the aeronautic industry it is possible to analyse vertical and horizontal relationships among the different firms that contribute to the aircraft production.

Vertical relationships occur between the leader firm and the other firms taking part in the aeronautic program. This type of relationships underlines a complex and hierarchical organization at the base of aircraft production system.

The supply chain can be depicted as a pyramid (Figure 2.1) where at the top there is a leader firm (as Boeing and Airbus) or a consortium that is responsible for the whole program and the assembly of the aircraft[2]. Furthermore, the leader firm organises the flow of the parts, components and systems; stores all products' relevant information in order to have the history of each component; manages relations with the final customer (airlines or airlines leasing companies).

[1] EADS is the consortium owner of Airbus. Actually, on January 02nd 2014, EADS was rebranded as the Airbus Group.

[2] It will have the responsibility for the certification of the final product by an international institution (the Federal Aviation Administration or European Aviation Safety Agency).

The first level is divided into three sub-sectors (airframe, equipment and avionics and engines) with their own structure and a degree of autonomy associated with the details of the program. In this level there are those large firms (as General Electric Aviation, Rolls-Royce, Honeywell and Pratt & Whitney for the engine sector) that realise (or assemble) complex parts of the aircraft, such as the engine (or wings, tail, fuselage sections, …). These firms, on the base of all program specifications received from the leader, decide what they will produce in-house and what will be outsourced to third level suppliers. They can choose the second and third level suppliers[3], but they must deliver to the leader all parts and components realised with the related information so that it is easy to understand if the conditions of the contract and the accuracy of the production process are respected.

The second and third level is generally constituted by medium (and small) firms; their work is mainly coordinate and checked by their customer, and in many cases also by the program leader, in order to verify the quality standards and the production processes.

Horizontal relationships among firms that belong to the same pyramid level changed and developed over the last 50 years (Esposito, 2004). In the 1950s, an aircraft was designed by one firm which was able to sustain both technological and economical efforts. In this way, only one firm was responsible for the program, and co-operation agreements didn't yet exist. Today, aerospace industry is completely different: this is characterised by collaborative and competitive relationships among firms, in order to spread, in an easier way, technologies and know-how within the industry. For example, Honeywell and Rolls-Royce are competitors, but they might collaborate and trade each other too.

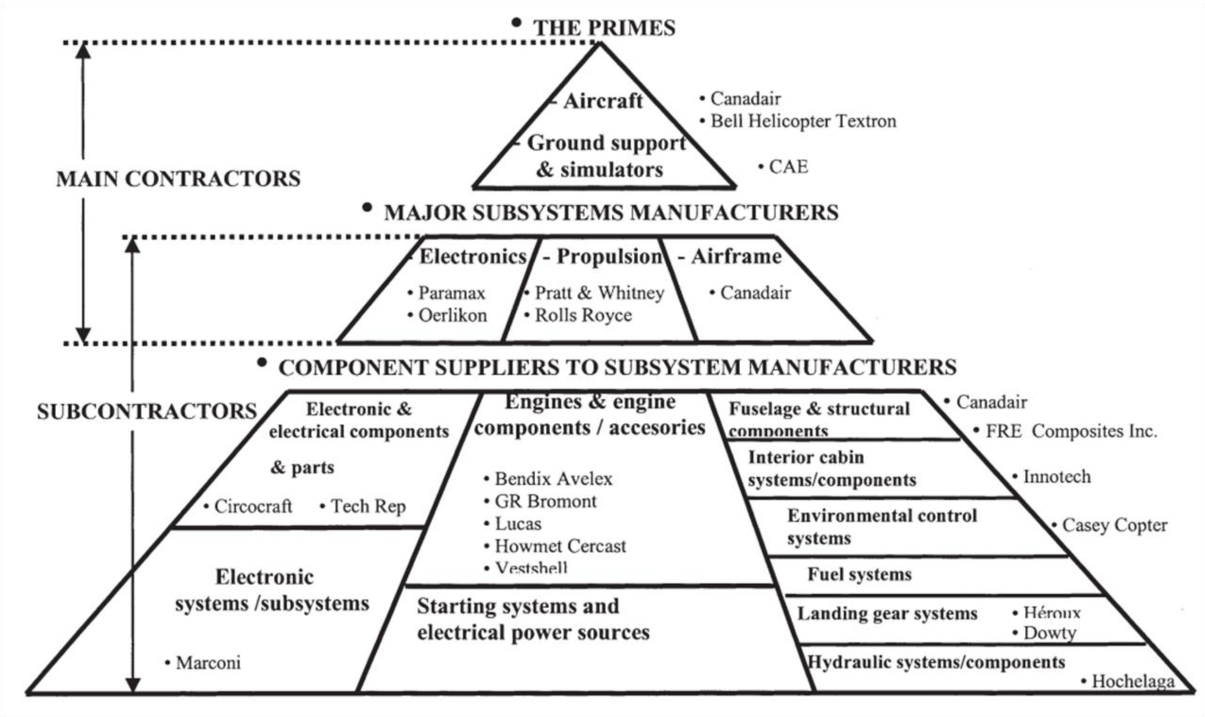


Figure 2.1: Structure of Quebec' s aeronautical industry. Source: Amesse et al., (2001)

[3] In collaboration and with the approval of the leader firm.

2.1.2 Aircraft lifecycle

According to studies conducted by Dutta and Wolowicz (2005), and Stark in 2005, the product aircraft lifecycle, from a manufacturer's point of view, comprises five phases:

1. *Conceptualization phase*, in which the market trends, needs and requirements are identified and a product design concept is realized;
2. *Definition phase*, in which the detailed design of the product and of its main components and the manufacturing processes and the development of a virtual and real prototype are realized;
3. *Realization phase*, that includes the production and the subsequent storing;
4. *Support phase*, in which the manufacturer is responsible for the maintenance of the product;
5. *Retirement phase,* where the product is disposed.

In the aviation industry it is possible to identify three main stakeholders: the *airlines* that want to ensure safe operation, reduce operation and maintenance costs, and minimize the turn-around time; the *aircraft manufacturers* that aim to reduce the development time of the aircraft lifecycle and cost; at last the *MRO service providers* that seek to provide a serviced aircraft at minimum cost and the shortest turn-around time.

Each of these actors has its own database and IT system, as you can see in Figure 2.2. Hence, during the life of a product, a lot of data are generated and shared throughout the extended enterprise, such as CAD data, specifications, engineering simulations, bill of materials, quality documents, defects, and many others etc.

In this scenario, product lifecycle management systems (PLMs) work as a business approach: they integrate people, processes, business systems and information in order to manage the entire lifecycle of a product across enterprises.

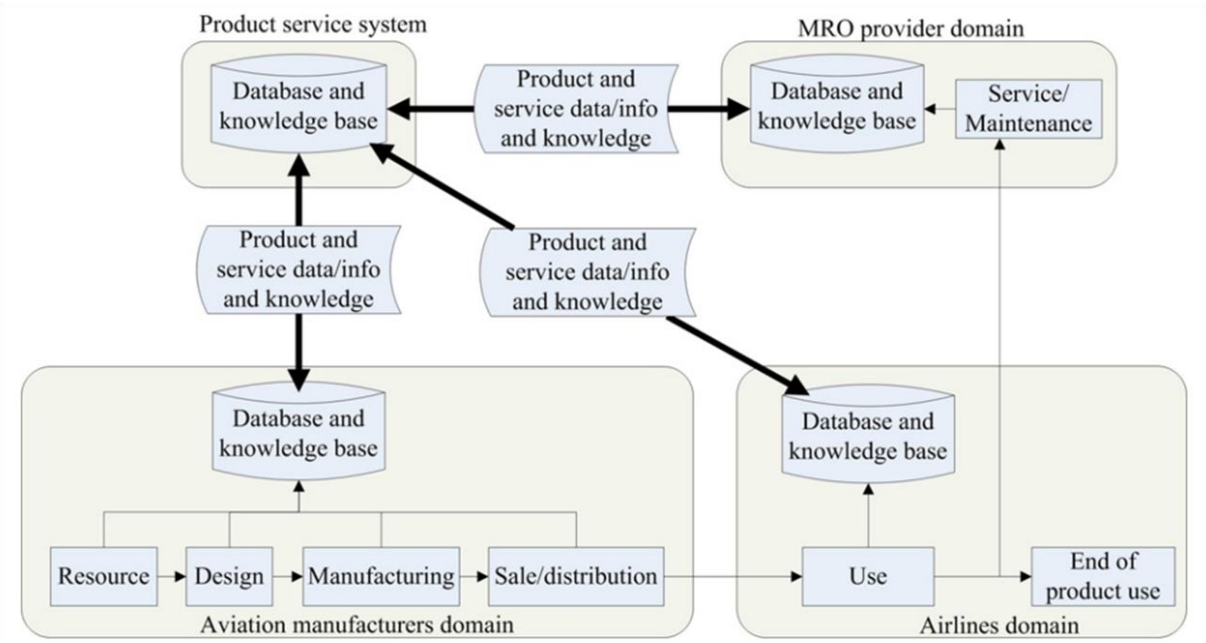


Figure 2.2: Information and knowledge provision and sharing. Source: Zhu et al., (2012).

According to a study conducted by Cizmeci in 2005, although the average economic life of an aircraft is 20 years, an aircraft can operate for as much as 50 years if it is well maintained (in accordance with federally regulated maintenance standards). So the aerospace supply chain gets support from the aftermarket industry (Maintenance, Repair and Overhaul business sector) which handles the aircraft maintenance and their up-gradation.

2.1.3 Maintenance, Repair and Overhaul

Lee et al. (2008) argue that maintenance is “the process of ensuring that a system continually performs its intended function at its designed-in level of reliability and safety”. To be more clear, the maintenance activities on aircraft are short enough to allow them to remain available for scheduled service.

In particular, there are two different types of maintenance:

- the scheduled maintenance, that is conducted at pre-set intervals in order to ensure the aircraft safety (this is a preventive form of maintenance);
- the unscheduled maintenance, that is carried out in case of breakdowns and requires a longer time than scheduled maintenance since it may entail extensive testing, adjusting and a replacement or overhaul of parts or subsystems.

On the contrary, overhaul represents the biggest and most labor-intensive maintenance event; it can only be performed by maintenance organizations able to satisfy special qualification requirements. For example, to overhaul an aero engine it is necessary to remove, disassemble, clean, inspect, repair and test it using factory service manual approved procedures; when the engine is overhauled it will perform as new.

It is possible to put in evidence three different levels of MRO service providers:

- Original Equipment Manufacturers (OEM)[4];
- Specialized third party contractors;
- Small enterprise for minor MRO activities.

Table 2.1: Engine primary maintenance processes. Source: Batalha, (2012).

Primary Maintenance Processes	Method	Application Methodology	Action
Hard Time (HT)	Preventive	Hour, Cycle or Calendar Limits	Remove for SV[5]: • Discard LLP[6] • Overhaul • Other maintenance task
On-Condition (OC)	Preventive	Inspect/Cheek/Verify against standard: • Hardware • Performance parameters	Check/correct defect: • Replace component LRU[7] • Other line maintenance item Remove engine for SV

[4] An Original Equipment Manufacturer manufactures products or components that are purchased by another company and retailed under that purchasing company's brand name.

[5] Shop Visit

[6] Life Limited Part

[7] Line Replacement Unit

Primary Maintenance Processes	Method	Application Methodology	Action
Condition Monitoring	Predictive	ECM[8]: Performance parameters trend/trend shifts evaluation	Check/identify causes of trend shifts; Correct defects Check parameters against limits

The objectives of all MRO service providers can be summarized in the following points (Kinnison, 2004):

1. to ensure or restore safety and reliability of the equipment;
2. to have all products and processes information so that maintenance can be optimised when there aren't the right safety or reliability levels;
3. to have all information necessary to repair components or to design tooling if some items have to be repaired or replaced during the overhaul process;
4. to accomplish the previous objectives staying within time and cost budget.

More deeply, there are three primary aircraft, component and engine (component or item) maintenance processes:

- *Hard Time (HT)* - some tasks have to be mandatorily performed at fixed intervals;
- *On Condition (OC)* - periodic checks on equipment, component or engine are carried out in order to monitor its conditions; the part checked will be removed when one parameter exceeds certain established limits (i.e., lubricant oil leakage) or when there is a reduction of reliability (i.e. caused by a Foreign Object Damage) and imminent failure;
- *Condition Monitoring (CM)* – collection and analysis of ex post facto data of a set of components using a reliability or performance evaluation programme, in order to assess their behaviour and to take corrective action.

In the Table 2.1 is presented the use of engine primary maintenance process to control engine operation and maintenance.

HT and OC are a priori and preventive monitoring processes, aiming to remove the component before it fails; while CM maintenance is not intended to prevent a failure, but to assess ex post facto the population behaviour. Furthermore, maintenance can be even classified as:

- *on-aircraft maintenance* if it is performed on or in the aircraft itself, with or without taking the aircraft out of service;
- *off-aircraft maintenance* if it entails the overhaul of the systems removed which can be temporarily put out of service.

[8] Engine Condition Monitoring

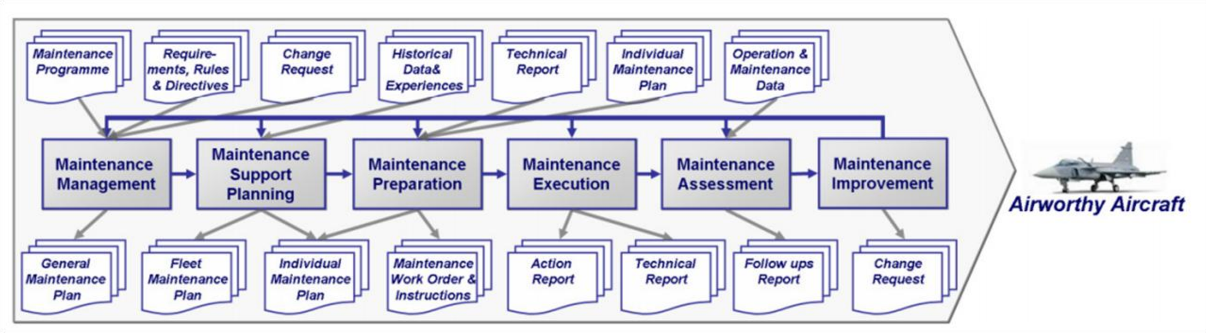


Figure 2.3: Example of Aircraft Maintenance Process. Source: Candell et al., (2011).

In order to measure the aircraft availability (AA), and the MRO service quality, it is usually used the formula AA = MTBF/(MTBF+MTTR), where MTBF is the *Mean Time Between Failure* and MTTR is the *Mean Time To Repair.* Hence, the aircraft availability can be improved either increasing the MTBF, that is improving the quality of the MRO service, or decreasing the MTTR, reducing the turn-around-time[9] required to complete the MRO service, or both.

To understand better the considerable role of the maintenance process in terms of quantity of information, the JAS39 Gripen case study is taken into account (Candell et al., 2011). This shows as the maintenance process may be described by six phases (see Figure 2.3): maintenance management, maintenance support planning, maintenance preparation, maintenance execution, maintenance assessment and maintenance improvement.

All these sub-processes consist of different sets of activities (each with its own information packet), which are interrelated each other and adapted to fulfil requirements from different stakeholders.

2.1.3.1 MRO market

MRO service is becoming a key market within the aerospace industry so that it can no longer be ignored.

As the lifespan of an aircraft could be higher than 30 years, it is clear that profitability in the aerospace industry is not just from the sale of aircraft, but also from maintaining them for an the entire lifespan.

In Figure 2.4 it is showed the trend for MRO spending: the available market is growing to about $65b by 2020 at 3.8% CAGR. Moreover, by 2017 the fleet will exceed 27,450 active aircraft (2007 World MRO Forecast).

[9] Period for completing a process cycle (such as repair or replacement of a component or equipment).

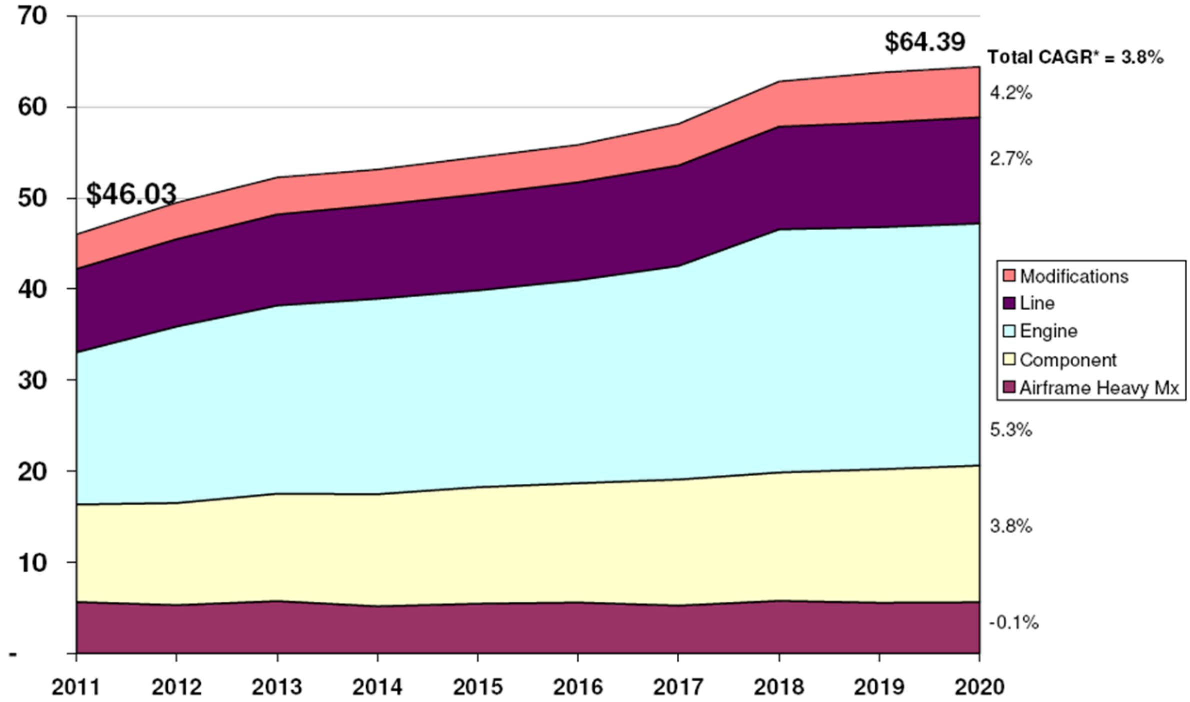


Figure 2.4: Estimated Worldwide MRO Spending. Source: (Khwaja, 2011).

This growth is "particularly strong in India and China, followed by Asia, Europe and North America, with less growth in North Africa and the Middle East" (Phillips, 2008, para. 9). The following Figure 2.5 regards the MRO supply chain structure over the decade, pointing out the market share ($B) for the different commercial aircraft segments[10] and the increasing role of outsourcing activities. The greatest share of revenue from MRO is derived from engine maintenance.

[10] The commercial aviation MRO industry has four segments:

1. Engines. "Engine maintenance includes dismantling, inspecting, assembling and testing aircraft engines (Carpenter & Henderson, 2008)."
2. Line Maintenance. "Line maintenance diagnoses and corrects troubles on the aircraft and carries out minor and major aircraft checks and repairs" (Carpenter & Henderson, 2008).
3. Components. "Component maintenance refers to repairs made to components such as wheels, brakes and interior components (Carpenter & Henderson, 2008)."
4. Heavy Maintenance. "Heavy maintenance encompasses structural modifications, landing gear repair, engine changes and regular calendar checks (Carpenter & Henderson, 2008)."

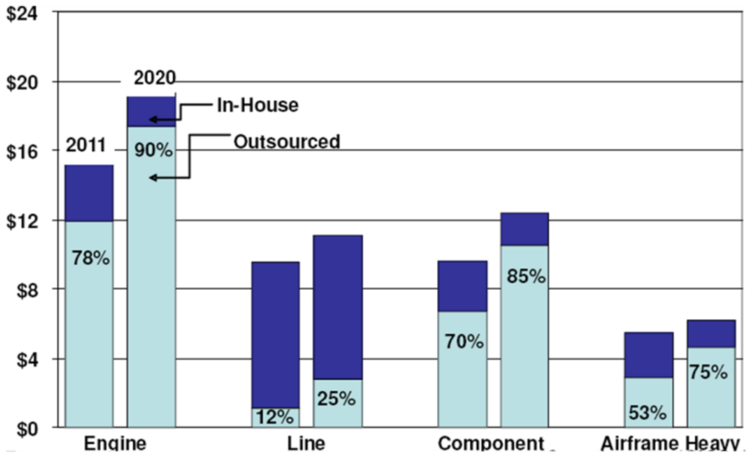


Figure 2.5: 2011-2020 MRO Supply Structure by Market ($B). Source: (Khwaja, 2011).

Similar arguments can be referred to the military business segment. The global military aircraft fleet exceeded 39,000 aircraft with maintenance on these aircraft costing governments $60.7 billion (Chrisman, 2008). The global military maintenance market will increase less than 1% (Figure 2.6). This slower trend depends on three (conflicting) trends: the decline in reset dollars, the fleet reduction and an increase due to ageing aircrafts.

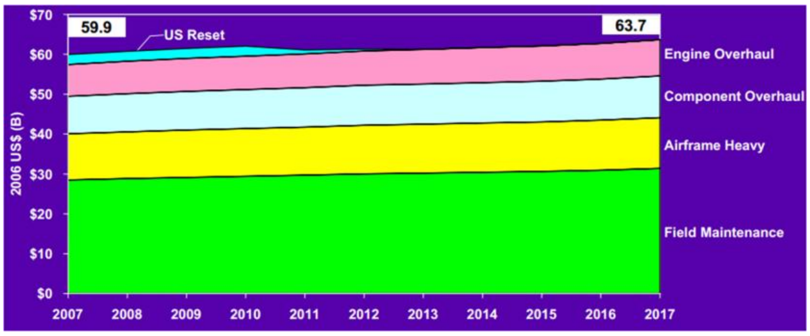


Figure 2.6: Global Military Maintenance Market Forecast 2007 – 2017 ($B). Source: (Khwaja, 2011).

Hence, taking into account the overall growth of world airline fleet and the increasing aircraft average age, the maintenance segment will likely overbear the other segments in the long run.

2.1.3.2 MRO supply chain

In aircraft MRO supply chain the flow of materials occurs in two directions, from customer to supplier and from supplier to customer, defining a closed loop supply chain (this is true excluding the component suppliers who send products to their customers, the MRO service provider, getting money in return) (Hayek et al., 2005). This is in contrast to standard supply chain models of consumer products in which there is a main one-way flow of materials towards the customer. Besides, while in consumer supply chains the transactions between customer and supplier has a well-defined sequence (see Figure 2.7), in aircraft MRO supply chain the transactions differs significantly, since some materials are purchased, others are sent to be repaired, others may be recycled or disposed of altogether.

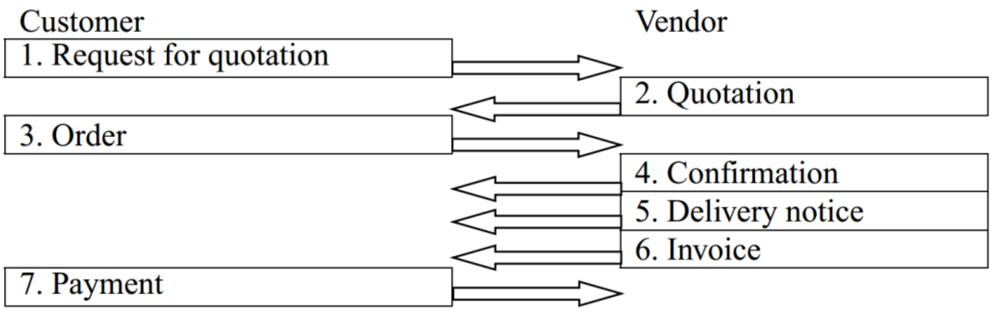


Figure 2.7: Transactions for the consumable Purchase Order process. Source: MacDonnell and Clegg, (2007).

The problem is that many current automated systems (such as ERP ones), used within the organizations to perform routine aircraft supply chain operations, use the standard "consumer products" purchase order (PO) model and modify it in order to approach the real process. In this way two major problems can arise: the first one is that the repair order process needs to be managed manually since there isn't a customized system conformed to the process; the second one is associated with the need to dispose of interconnected customers' and suppliers' systems to perform automatic transactions between organizations and to optimize them.

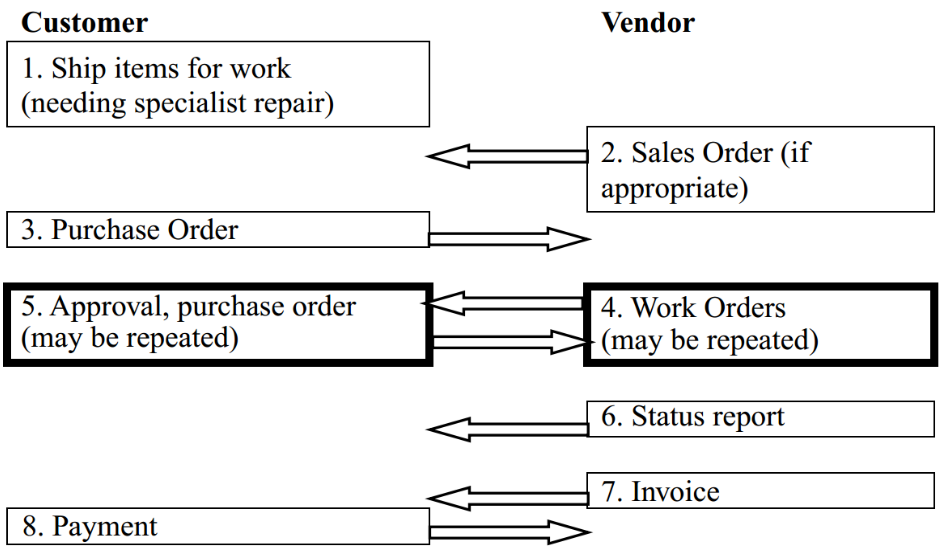


Figure 2.8: Transactions for the MRO Purchase Order process. Source: MacDonnell and Clegg, (2007).

In the Figure 2.8 a core MRO process in the aeronautic industry is shown. According to this example, the customer sends an "out of order" (without a specific PO11) item to the service provider; it generates a sales order (if appropriate) after a detailed inspection of the item12;

[11] In the specific case, the customer and the service provider have signed a 'framework agreement' of the type 'time and material contracts' (see next section 3.2.1) through which the second will provide the MRO service to the first one for a certain period and on a certain number and types of engines. The framework agreement states the general quality of the services provided (costs and time).

[12] During the inspection all parts of the engine is controlled and the complete list of the 'to be changed' parts is filled.

the customer replies with a PO and the actual transaction begins. As the work progresses, work orders (WOs) are generated by the service provider and attached to the sales order. Hence these changes are communicated to the customer who (in same cases) can modify the original PO.

All this highlights how the MRO process is complex and uncertain, with a possible repeating loop (between steps 4 and 5) that needs of a flexible database to manage the information transactions. Moreover this process is also characterized by frequent updates of the activity plan then also inventory is very critical with respect to the final performances.

2.1.3.3 The role of ICT solutions

A central issue for maintenance and support service providers concerns the management of the growing amount of information generated by the development of highly complex aircraft systems and by stakeholders requirements in terms of dependability increase and Life Support Cost (LSC) decrease. To face these problems, maintenance and support actors are depending more and more on ICT solutions. These are one of the main elements not only to improve the effectiveness and efficiency of the maintenance process for complex systems with a long lifecycle, but also to reduce the associated risks and to contribute to a more efficient business process. According to Liyanage et al. (2003) and Soderholm et al. (2007), the benefits linked to the use of ICT systems in this business segment are:

- more controlled content sharing;
- information exchange and knowledge management;
- coordination of maintenance process with other processes;
- connection to strategic business objectives and external stakeholder requirements.

Unfortunately, despite the new aircraft complexity, the integrated digital system and the air-to-ground real-time communication technologies, a large part of information used by maintainers in aeronautic industry is still paper documents or "paper-on-screen" solutions. Anyway a lot of industrial innovation projects are already on going aimed at increasing the automation of the MRO process, that is automatic supply chain data processing and decision making.

In general, while the technology is pervading the aeronautic industry operations, its application is strongly focused on supporting business of firms perceived as single actors. On the contrary, collaborative systems enabling supply chain participants to speed up cooperative procedures have very low applications. The main reason is that cooperative procedure needs sharing confidential data among partners. Indeed data sharing in the aeronautic is strongly controlled for, at least, 3 reasons: 1) aeronautic industry has a national security relevance and many national and international (European and US) laws limit and require to control the flow of goods and related information, 2) data related to a specific aeronautic program are strongly controlled and maintained confidential by all supply chain participants as driver of competitive advantage, 3) aeronautic business relationships are about face to face trust more than IT trust.

Further, the MRO business sector is characterized by the fact that different competing airlines can be customer of the same MRO service provider. In this situation, providing confidential data to the service provider, in example data about the status of the fleet to plan overhauling, means to give information on profitability to someone in contact with competitors. The current approach to systems' security and data protection cannot provide effective guaranties about who accesses data in the different stages of the collaboration input data sharing, result computation and distribution and storage.

The technological challenge of this project is to develop new supply chain cooperation systems, based on secure computation. This technology is based on the computation of encrypted data and can be applied in planning the MRO service to different customers without knowing the actual status of the aerofleet nor the capacity usage of the service provider, not the inventory status.

2.2 Consumer Goods Industry

Consumer goods industry is a category of stocks and companies that relate to goods purchased by individuals rather than by manufacturers or industries. This sector includes companies involved with food production, packaged goods, clothing, beverages, automobiles and electronics. Household industry is listed under consumer goods industry.

The global household appliance industry is expected to experience a CAGR of 6.1% over the next years and the industry revenue is forecasted to reach an estimated $384 billion in 2017.

The household appliance industry consists of cooking appliances, refrigeration, laundry appliances, home comfort appliances, and other product groups.

The industry is capital intensive and fragmented as thousands of players are competing with each other to sustain and improve their market share. Increases on the consumer incomes and changing lifestyle are the main drivers of the demand. Maintaining the balance between price and quality is one of the biggest challenges for the industry.

2.2.1 Major Domestic Appliances (MDA) Market

The size of the world's MDA9 market (which consists of the sales of major 9 domestic appliance product groups: washing machines, tumble dryers, dishwashers, cooling, freezers, cooking, built in hobs, hoods, microwave ovens) was USD 176 billion in 2012 and is expected to reach USD 189 billion in 2014, mainly due to the expected growth in China, India, Africa, Russia and CIS.

Beko (one of the main brand of Arcelik) brand's ranking in the European market was 22nd on year 2000 with a market share of 1,1% in terms of units sold. Its share has grown continuously over the years thereafter, which was 7% in 2013 and the ranking of the brand moved to 3rd position in the market.

2.2.2 Turkish White Goods Market

The market has grown in 2013 to a number of approx. 6.8 million units which is approx. equal to the 20% of the market of Eastern European and Russia.

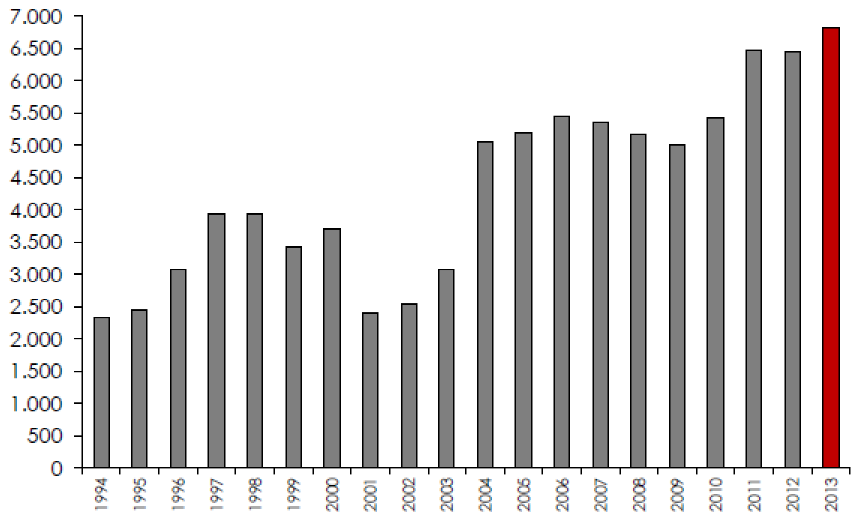


Figure 2.9: Turkish diffusion into the market.

Main driver behind the growth of the market is the county demographics.

Main Demand Driver : Demographics

- ✓ Population : ~76 million
- ✓ Population growth rate : 1,2%
- ✓ Population under age 30: 50 %
- ✓ Population under age 15: 25 %
- ✓ Number of households : 19,8 million
- ✓ New household formation: 2 %
- ✓ Number of marriages: ~ 600.000

Construction permits for flats (000)

2008	2009	2010	2011	2012	2013
503	518	907	650	751	814

Source: Turkstat

	Number of Households (mio units)	Population (mio)	Average Member per Household
Turkey	19,8	75,6	3,8
Germany	40,0	81,6	2,0
France	27,2	63,0	2,3
UK	27,4	62,2	2,3
Italy	24,6	60,6	2,5
Ukraine	20,0	45,8	2,3
Spain	17,6	46,2	2,6

Figure 2.10: Drivers of the consumer goods industry growth.

2.2.2.1 Arcelik – Global Network

Arcelik, Turkey's leader household appliances manufacturer, engages in the production and marketing of durable goods, components, consumer electronics and after-sale services. Its products include white goods, electronic products, small home appliances and kitchen accessories, such as refrigerators, freezers, washing machines, dishwashers, aspirators, vacuum cleaners, coffee makers and blenders.

Arcelik offers products and services around the world with its 25,000 employees, 14 different production facilities in five countries (Turkey, Romania, Russia, China and South Africa), its sales and marketing companies all over the world and its 10 brands (Arcelik, Beko, Grundig, Blomberg, ElektraBregenz, Arctic, Leisure, Flavel, Defy and Altus).

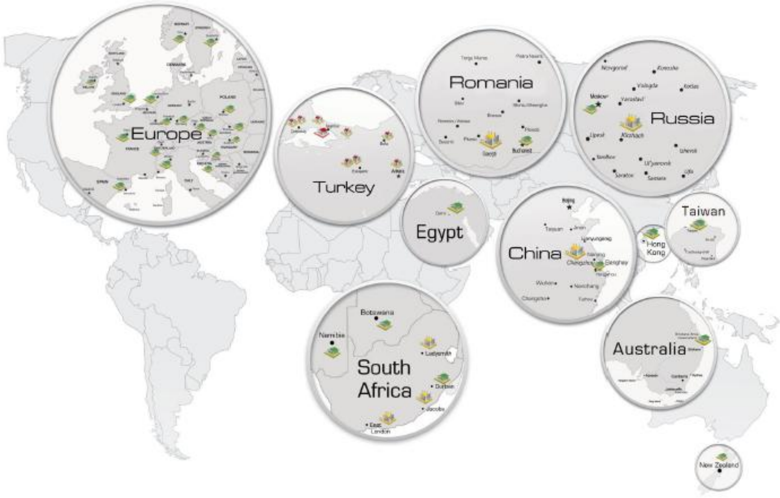


Figure 2.11: Arcelik presence in the world.

The company is controlled by Koc Holding, Turkey's largest industrial and services group with a $38.865 Mn turnover in 2010, is the market leader in Turkey's appliance sector with its Arcelik and Beko brands. It is also the third largest household appliances company in Europe.

2.2.2.2 Arcelik's Competitive Advantages in the Market

- Arcelik is strategically located in larger markets comprising ~40% of the global market share (Africa, Middle East/ Turkish Republics, East Europe and West Europe).
- Its logistics cost is significantly lower than Asian manufacturers due to shorter distance to target markets.
- Arcelik's most labour intensive functions including headquarters and production plants are located in low labour costs countries:
  - Labour costs in Western Europe ranges from €35 – 44/h
  - Labour costs in Eastern Europe are €6/h in average
- In addition, in those low cost counties the hours actually worked per year are significantly higher, resulting in higher utilization of plants capacity.
- Arcelik is also benefiting from economies of scale by keeping larger plants under one roof.

2.2.2.3 Supply Chain Management in Arcelik

Supply chain network can be differentiated by several dimensions; by the nature of the markets, by product ranges, by sourcing types and also by the agreements and the content of the business done with transport service providers.

There are mainly two kinds of flow throughout the chain: flow of goods and flow of information. These flows together fulfill the requirements of the whole system. On one hand, flow of goods starts with suppliers of suppliers and ends at the final customer. On the other hand, information flow starts from customer side and goes upstream towards the suppliers.

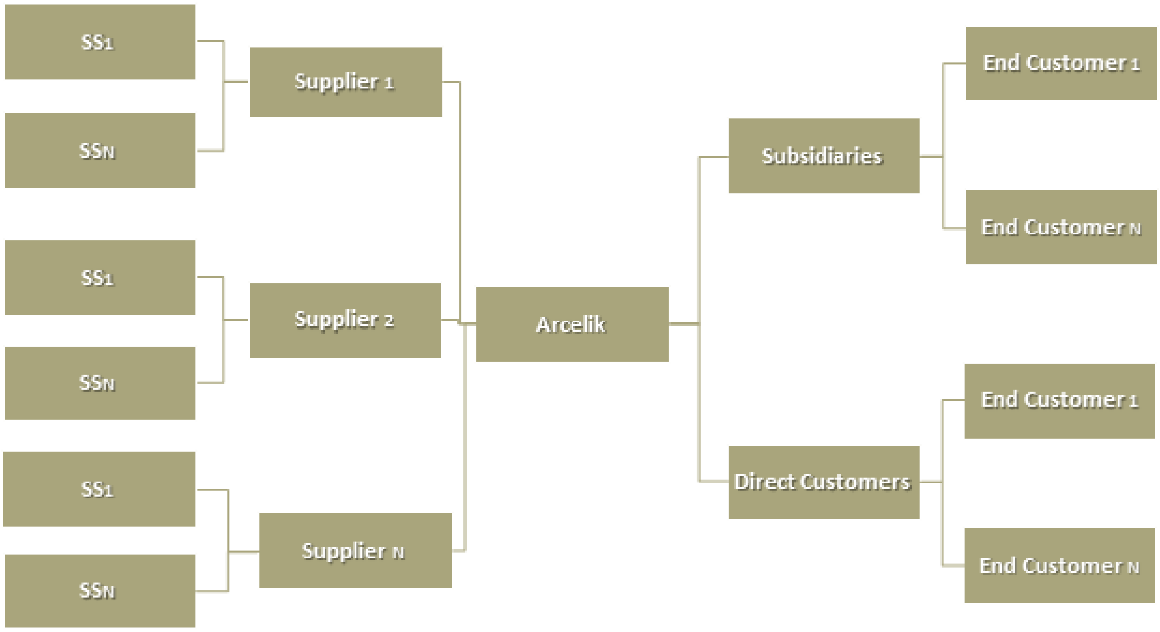


Figure 2.12: Arcelik supply chain.

A comprehensive supplier management system is the basis for optimization of the collaboration between Arcelik and its suppliers. Supplier management is thus a crucial factor for the safeguarding of the competitive advantage of Arcelik through a continuous improvement of its supplier base. Arcelik selects, improves and finally become a party with its suppliers that achieve its quality requirements for raw materials at correct time and correct place with required amount of materials and suitable price.

On the other side of the chain, Arcelik works with two different types of customers: its subsidiaries and its direct customers. Subsidiaries are the outer layer of the Arcelik in export markets (i.e. BEKO LLC in Russia, BEKO PLC in United Kingdom, Defy in South Africa etc). These companies are responsible for sales and marketing of Arcelik products to the customers in their regions. Arcelik also have direct customers are established in any country. They are not a part of Arcelik but its customers.

Information is directly generated in the market by sales and carried to supply chain head office (Istanbul, Turkey) via subsidiaries and/or direct customers. International Order Management Department, Stock Planning Department, Demand and Production Planning Department and Logistic Departments, which are part of the Supply Chain Directorate, process the information and transfer it to the Production and Purchasing Departments. Purchasing go backwards to suppliers to get raw materials that are required for production.

Main targets of Arcelik supply chain are low operating costs, flexibility, consistent delivery performance and effective stock levels. The collaboration between logistics, sales and production planning is stronger with the help of an overall supply chain management approach. The costs must be lowered throughout the chain by driving out unnecessary expenses, movements, and handling. The main focus is the efficiency and added value, or the end-user's perception of value. The measurement of performance focuses on total system efficiency and the equitable monetary reward distribution to those within the supply chain.

2.2.2.4 The role of ICT solutions

Arcelik organizes 280.000 shipments and approx. sells 26 million products per year to more than 100 different countries. In order to achieve this, it has a supply chain network consisting of more than 1.000 suppliers from different countries, 18 subsidiaries, around 500 main direct customers of different sizes, around 3000 dealers and more than 500 logistics service providers.

As the business grows, the need for efficient, effective and secure collaboration between involved parties in the chain becomes more crucial for exchanging information to coordinate business activities. However interaction with business partners is still limited to manual efforts using e-mail, phone, and fax, or only partially supported by ICT solutions. Most of the documents are created and transferred through the chain manually. Delays in the information transfer and data reliability problems are mostly due to one-to-one communication, manual communication and data processing with a high risk of human errors. The major demand is to receive the necessary information from the business partners completely and on time.

A cloud based planning system will help to increase the transparency throughout the chain in a way that resources can be utilized more efficiently. The key functionalities for such a system relate to aspects of security. The security is extremely important because highly sensible data (such as strategic decisions about production and distribution, info on supply chain partners and their tariffs etc.) will be stored and shared through the cloud.

Chapter 3 Collaborative Supply Chain Planning in the Aerospace and Consumer Goods Industry

In this chapter, a general introduction to supply chain collaboration is given in subchapter 3.1, followed by the application of the theoretical concepts to the aerospace industry in subchapter 3.2.

3.1 Supply chain collaboration

In this subchapter, the theoretical basics regarding supply chain collaboration are presented. Section 3.1.1 introduces the general role of collaboration. In sections 3.1.2 and 3.1.3, two collaborative concepts are presented, namely *Collaborative Forecasting (CF)* and collaborative planning and monitoring, or more precise, the *Vendor Managed Inventory (VMI)* approach. The last section provides an outlook of the implementation of both concepts in the cloud.

3.1.1 The role of supply chain collaboration

In a traditional supply chain every enterprise decides individually on its production, inventory and delivery activities without considering different interactions at the other levels of the supply chain. Based on its sales, each company determines its demand which is then transmitted to the particular vendor. Hence, the order by the customer is the only immediate information for the vendor to plan his procedures (Holweg et al. (2005), p. 172). For meeting the demand, the enterprises usually hold safety stocks. Since along the supply chain every company calculates uncertainties in demand into their order placements, discrepancies between the customer's demand and the vendor's orders emerge at all stages of the supply chain. The placed orders fluctuate considerably more at the upstream levels than at the downstream levels of the supply chain. This phenomenon is commonly known as the bullwhip effect (Simchi-Levi et al. (2009), p. 154f). Higher costs due to higher safety stocks, lower service level and difficulties in planning the capacities are some of the negative results arising from the bullwhip effect (Simchi-Levi et al. (2009), p. 154; Alicke (2005), p. 99ff).

A possibility to eliminate or at least reduce the bullwhip effect is to develop collaborative initiatives between the parties of a supply chain (Disney and Towill (2003b), p. 647f). In the context of globalization, collaborations have gained in importance in recent decades. Advances in technology, increased consumer requirements and shorter product life cycles urged companies to focus on the whole supply chain than solely on their own enterprise (Simchi-Levi et al. (2009), p. 1). To ensure both their own supply and responsiveness regarding time-critical and cost-related criteria and therefore, to maintain competitiveness, the establishment of long-term partnerships and alliances is essential nowadays.

Supply chain collaboration is the alignment of individual plans and strategies of the involved parties. The stronger coordination and the overcoming of information asymmetries with partners shall conduce to improvements of the supply chain performance (Stadtler (2009), p. 5f). Additionally, the uncertainties in demand may be reduced by taking into account interactions at other levels of the supply chain. Better knowledge of the downstream demand enables the customer to facilitate the vendor's predictability skills concerning his production and delivery capacities by providing him with appropriate data. Reduced inventory and hence lower costs are potential benefits for the partners.

In this study, the main focus will lie on the concepts of Collaborative Forecasting and Vendor Managed Inventory. In research, additional related concepts are Quick Response (QR), Efficient Consumer Response (ECR), Continuous Replenishment (CR) and Collaborative Planning, Forecasting and Replenishment (CPFR) (Simchi-Levi et al. (2009), p. 254f; Elvander et al. (2007), p. 782f; Angulo et al. (2004), p. 101; Marquès et al. (2010), p. 548; Disney and Towill (2003b), p. 637). These concepts differ on the one hand in the scope of exchange of information and on the other hand to the extent the vendor is integrated in the decision-making process regarding replenishment (Alicke (2005), p. 167ff). However, these concepts are partly interpreted differently and even used synonymously by many authors (Marquès et al. (2010), p. 548f).

3.1.2 Collaborative forecasting

An important field for collaboration between members of the supply chain is Collaborative Forecasting (CF) which can be defined ‘as the purposive exchange of specific and timely information […] between trading partners to develop a single shared projection of demand’ (McCarthy, Golicic 2002, pp. 434–435). Operations all over the supply chain are influenced by final customer demand and CF is a way in which all concerned parties can join efforts to anticipate this key driver of their operations in a more accurate and effective way (Helms et al. 2000, p. 393).

In subchapter 3.1.2.1, basic characteristics of collaboration in the context of forecasting and a brief overview regarding the previously mentioned ‘Collaborative Planning, Forecasting and Replenishment’ (CPFR) concept are presented. Subchapter 3.1.2.2 points out how and which characteristics of a supply chain affect the performance of CF. Subchapter 3.1.2.3 takes a closer look at the ‘specific and timely information’ mentioned in the definition of CF with special focus on data privacy issues. Finally, subchapters 3.1.2.4 and 3.1.2.5 examine the potential benefits and risks that come with CF and how they could or should be distributed amongst the players.

3.1.2.1 Collaborative concept as an extension to traditional forecasting processes

Traditionally, each party on each stage of the supply chain has its rather isolated forecasting processes which are mainly based on data of historical demand that aroused from their direct customers. The problem with these orders from the next stage is that they are again results of an isolated forecast and in general don’t match the actual sales on the buyer’s stage. Instead, they tend to have a larger variance. This effect of demand distortion results in amplified forecasting numbers and dramatic swings in demand increasing with every step on the supply chain further away from the end customer. This phenomenon is known as the bullwhip effect (Lee et al. 2004, p. 1875; Barratt 2004, p. 38).

Besides this rather technical problem, forecasters have to deal with the uncertainty given by a constantly changing market environment. New products, promotions or other first-time events can’t be predicted by only using historical data (Helms et al. 2000, p. 394). However, these information do exist, and CF is an attempt to bring them together to create a single, more accurate forecast which is accepted by all collaborating members of the supply chain. In a collaborative forecasting process ideally all supply chain members add their particular expertise and information to find the best possible forecast. The information about end customer demand is shared with the upstream supplier, so demand distortion can be reduced drastically (Helms et al. 2000, pp. 393–395). This again will drastically reduce the bullwhip effect (Chen et al. 2000, p. 7).

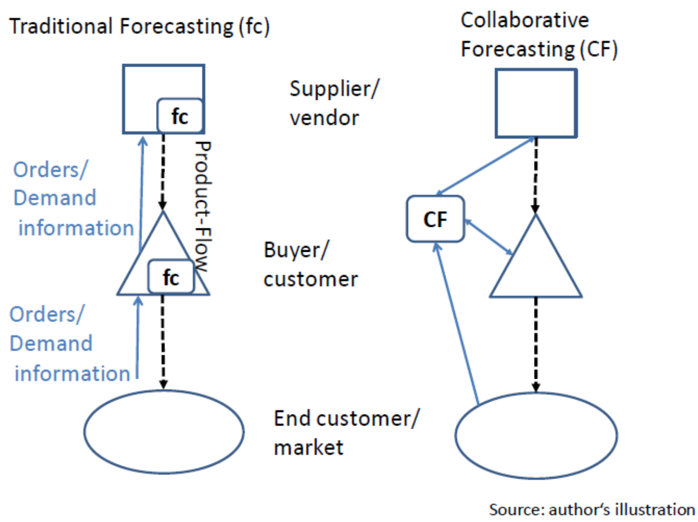


Figure 3.1: CF with one supplier and one buyer.

Yet, despite the theoretical benefits of CF are well known, the practical implementations are rather scarce (Småros 2007, p. 704). A basic form of CF is that the buyer shares his forecast with the upstream suppliers, who can interpret this information as advanced notification of future orders and adapt their production plans. This is based on the assumption that the buyer has more accurate information about the actual end customer demand due to its position further downstream. However, in this constellation the buyer might try to influence the production plans of his supplier by manipulating the shared forecasts. If there are no methods applied to make this behaviour unattractive for the buyer, the supplier has to expect it and as a consequence would not take the forecast seriously. Companies like SUN, Hewlett-Packard and Texas Instruments implemented this kind of CF within so called quantity-flexible contracts. The forecasted quantities could be re-adjusted within certain boundaries, to increase their accuracy and therefore the acceptance by the supplier (Lee, Whang 2000a, p. 8).

A more sophisticated method which comes into broader use mainly in the consumer goods industry is Collaborative Planning, Forecasting and Replenishment (CPFR). It describes in detailed steps how the collaboration should be implemented on the operational as well as on the tactical and strategic level. Once running and fed with the POS data as input, the model should in particular deliver one central projection for the retailer's orders. Human involvement is only necessary if one of the beforehand agreed exception rules has to be applied. Therefore, the suppliers can operate based on end customer demand information. This results in highly increased flexibility and a more efficient supply chain (Barratt 2004, p. 270; Seifert 2004, pp. 358–365).

General problems for collaborative concepts in practice are (Seifert 2004, pp. 367–368; Barratt 2004, p. 30):

- High investments in ICT needed,
- Implementation has proven to be too difficult,
- Failure to identify the right collaboration partners,
- Fundamental lack of trust between players,.

The latter argument caused Walmart to stop sharing its sales data with outside companies. Walmart was one of the first companies which implemented CPFR quite successfully but they started to fear information leakage through their former partners (Deshpande, Schwarz

2006, p. 2). Applications of encryption technology open a way to avoid this drawback of collaboration. They allow the computation of a joint forecast without the necessity for the companies to reveal their private information to each other (Deshpande, Schwarz 2006, p. 6). These privacy issues will be further discussed in 3.1.2.3

3.1.2.2 Key characteristics of the supply chain affecting CF

The potentials of CF depend on the structure of the supply chain network and on the characteristics of the relationships of related players within the network. The most basic form of a collaborative supply chain with one supplier and one buyer is illustrated in Figure 3.1. Traditionally, each party on each stage of the supply chain has its rather isolated forecasting processes which are mainly based on data of historical demand that aroused from their direct customers. The problem with these orders from the next stage is that they are again results of an isolated forecast and in general don't match the actual sales on the buyer's stage. Instead, they tend to have a larger variance. This effect of demand distortion results in amplified forecasting numbers and dramatic swings in demand increasing with every step on the supply chain further away from the end customer. This phenomenon is known as the bullwhip effect (Lee et al. 2004, p. 1875; Barratt 2004, p. 38).

According to Aviv (2007), key characteristics of the internal structure are:

- How the access to demand information is partitioned amongst the players and how these information streams are correlated,
- The flexibility of the supply side,
- The internal service rate.

In a model consisting of a manufacturer and a retailer, the performance of the supply chain is measured with a scorecard including measures of operational efficiency such as inventory holding costs on both levels, capacity utilization and adherence to production plans and a penalty cost for unfilled end customer demand (Aviv 2007, pp. 780–781). In this setting it is shown that CF yields better scores, if the manufacturer has the relatively larger explanatory power. Explanatory power in this context refers to the ability to reduce the uncertainty by using the available market signals. A possible explanation for the influence of the informational imbalance is, that shortages are more costly for the retailer than for the manufacturer. Hence if the benefits of CF are strong on the retailer's side because his isolated forecasts were notably worse, the benefits for the whole collaboration are strongest (Aviv 2007, p. 788). The value of collaboration for the supply chain is highest, if the forecasting information of both players shows the lowest correlation. This is the case if the forecasting capabilities are highly diversified (Aviv 2001, p. 1337). Hence, the different information streams work as compliments and the players can profit from information sharing (Yue, Liu 2006, p. 662). The access to demand information decides on the quality of the isolated forecasts. In similar supply chain constellation, extended by a direct distribution channel for the manufacturer, Yue and Liu (2006) show, that CF yields best results if the accuracy of the retailer forecast is low, the one of the manufacturer is high and the correlation between them is low.

The flexibility of the supply side is important to capture financial benefits from CF. If the manufacturer can't react on the additional information provided by CF, the benefits will stay low. If the manufacturer is for example strictly limited regarding flexibility of his capacities, the sharing of historical demand data from the retailer is of minimal value because the supplier can't act upon it (Aviv 2007, p. 788).

An internal service rate which is fixed on a high level limits the potential benefits of CF for the overall supply chain. To keep such a high rate of demand fulfilment, the manufacturer is forced to keep high safety-stock inventories which limit his flexibility. All participating parties should carefully analyze the potentials that lie within an adjustment of the service rate expectations. By lowering the service rate, the profits for the supply chain as a whole can be increased, though the manufacturer could face a loss. A way to deal with this issue is the installation of a benefit-sharing mechanism to divide the additional benefits and thereby set incentives for all parties to keep up the collaboration. The optimal internal service level is influenced by two important factors: relatively higher costs for inventory on the retailer side and low flexibility of the supplier make it efficient to install safety-stock inventory further upstream, i.e. on the manufacturer's level, which comes with a higher internal service rate (Aviv 2007, p. 791).

3.1.2.3 Information exchange

Before analysing the specific types of information relevant for CF, first a categorization of how they could be exchanged is presented. Lee and Wang (2000a) distinguish three models for information exchange:

- Information transfer model,
- Third party model,
- Information hub model.

In the information transfer model, the information is centralised in a database under the control of one of the partners. The information from the other collaborating parties is transmitted there and then used for decision making. This structure is similar to the EDI-based transaction model, but EDI standards have to be extended to deal with the more complex data types which are needed for CF.

The third party model involves a player other than the collaborating partners whose main role is to collect information in a centralised database, to process it and make the results available in the supply chain. The advantage of this solution is that the collaborating partners don't have to reveal any private information to each other. If the original data can't be deduced from the processed results it will remain private unless there is an information leakage from the third party.

The information hub model is similar to the third party model with the difference that the third party is replaced by a system. It does not have to exist physically and can rather be seen as a logical entity. The implementation could happen in form of a cloud-based service. This model eliminates the risk of information leakage through the third party. If the transaction protocols (e.g., based on secure multiparty computation) are set up properly and the original data can't be deduced from the processed results, the partner can benefit from the collaboration without giving up the privacy of their data.

An important part of any collaborative approach is the identification and categorization of the types of information that might be relevant for the process (Helms et al. 2000, p. 398). For CF, the information reported in the Table 3.1 should be considered (Lee, Whang 2000a, pp. 3–8; Deshpande, Schwarz 2006, p. 8; Atallah et al. 2004, p. 2).

Most of the information listed in Table 3.1 is strictly private by nature, so companies face a trade-off between the potential benefits of sharing their private information and the reasons for keeping it private. Common arguments against sharing are the fears of weakening their negotiating position (e.g., in case of over-capacity), embarrassment and violating anti-trust regulations. Companies also see the risk that information about corporate performance and strategies might be leaked to competitors which would weaken their competitive position (Atallah et al. 2004, p. 2; Deshpande, Schwarz 2006, p. 2).

Type of information	Reason for sharing	Threat through sharing
Historical demand data	Used for forecasts based on time series analysis	Leakage can reveal strategically relevant corporate insights
Market signals	Used for forecasts based on regression analysis	Leakage may weaken competitive advantage
Promotion plans	Important factor for variable demand not predictable using the data above	Leakage enables competitors to take action against the campaign
Production cost structure	Needed if the forecasts should take optimal lot sizes into consideration	Weakens bargaining position of producer if larger margins are revealed
POS data	This information about actual customer demand is the main driver of future upstream orders	Embarrassment; Leakage can reveal strategically relevant corporate insights
Demand forecasts (if not computed collaboratively based on the data above)	Sharing of end customer demand forecasts with upstream partners as a basic form of CF	One of the partner might have an incentive for manipulation
Inventory levels and related cost structure	Important to foresee bottlenecks and to integrate forecasts efficiently with production planning	Weakens bargaining position, e.g. if surplus is revealed
Production/delivery schedules		Weakens bargaining position, e.g. if idle capacity is revealed

Table 3.1: Relevant information in the context of CF.

A way to avoid the before mentioned arguments against collaboration, is by combining the information hub model with a privacy-preserving method to compute the shared results. Such a method can be developed with means of Secure Multi-Party Computation (SMC) which is defined by Deshpande and Schwarz (2006, p. 6) as follows: "Secure Multi-Party Computation (SMC) provides a framework that enables supply-chain partners to make decisions that achieve system-wide goals without revealing the private information of any of the parties, and without the aid of a "trusted third party", even though the jointly computed decisions require the information of all the parties. SMC accomplishes this through the use of so-called "protocols". An SMC protocol involves theoretically-secure hiding of private information (e.g., encryption), transmission, and processing of hidden private data. Since private information is never available in its original form (e.g., if encryption is used to hide the data, it is never decrypted), any attempt to hack or misuse private information is literally impossible".

A CF process, in which the joint forecasts are computed using SMC protocols on an independent information hub, offers the benefits of collaboration, without the need for open exchange of sensitive data between any collaborating partners. Only the results of the computation based on the joint information are revealed amongst them.

Even though the process itself might be theoretically secure, there could still be a possibility for one or more of the involved players to deduce the private input data of one of the others from the results and their own inputs. This is called ‘inverse optimization’ (Deshpande, Schwarz 2006, p. 5). According to Pibernik et al. (2011), a secure CF process should provide both: secure computation according to the foregoing definition and robustness against inverse optimization.

Any form of CF requires trust in the capabilities and willingness of the partners to provide high-quality data (McCarthy, Golicic 2002, p. 434). Without the open exchange of information between collaborating partners as in a secure CF process, this need for reliance increases because there is no direct way of controlling the partner’s input data. It might be helpful to exchange meta information about the process of data gathering and the used techniques to address these concerns.

3.1.2.4 Benefits of CF and Incentive Schemes

It can be stated that CF has the potential to significantly improve the performance of the supply chain as a whole. The consolidation of information improves the quality of the forecast, thus giving the companies a better foundation for any further decisions which are based on the forecast (Deshpande, Schwarz 2006, p. 1). Though, these benefits in general don’t spread equally, let alone proportional to the invested efforts, between the collaborating partners. It might as well happen that one party would face losses through the implementation of CF although the supply chain as a whole performs better. Therefore it is necessary to set up mechanisms which enable a distribution of the benefits in a way that all parties are incentivised to collaborate (Aviv 2007, p. 793). This issue will be further regarded in the second part of this subchapter after an analysis of the potential benefits. Prior to that the benefits identified by a theoretical approach including stylized modelling are presented, followed by the benefits, which were found by analysing practical implementations of CF.

Lee et al. (2004) state that ‘“double forecasting” can be a key driver of the bullwhip effect. A main benefit of CF is that it eliminates this “double forecasting” as a strong source for additional uncertainty within the supply chain. Forecasts based on combined information yield more accurate results which allows lower safety buffers in inventory or capacity which lowers associated costs (Seifert 2004, p. 366). In his work on the benefits of CF, Aviv (2007) uses extensive simulations, run on a single-stage model with one supplier and one buyer who share their individual market signals to predict the fluctuations from the underlying autoregressive demand progress. He estimates the average improvement achieved by CF in the overall supply chain at about 4%. Though, the benefits strongly depend upon the different parameter constellations.

An average improvement of 4% in terms of inventory holding costs, capacity utilisation, adherence to production plans and penalty costs for unfilled end customer demand is already noteworthy, also because it can still be considered rather conservative. This is for two main reasons: firstly, the model did not capture the influence of sharing information about promotion, price setting, plans or merchandise campaigns or the introduction of new products which are key driver of demand distortion and therefore have a strong impact on the potential of CF (Kurtuluş et al. 2012, p. 6; Lee et al. 2004, p. 1883). Secondly, CF partnerships often come with improvements in ICT which enables higher levels of supply side agility. The impact of this side effect can be significantly higher than the results indicated by the simulation. According to this, Cachon and Fisher (2000) state “[…] that the same information technology that facilitates information sharing also contributes to the reduction of lead times and shipment frequency by reducing the time and cost to process orders.”

In a make-to-stock scenario as described by Mishra, Raghunathan and Yue (2009), CF affects only the pricing decision. It is shown, that in combination with the right benefit sharing contract, CF can be very valuable to both collaborating partners. Especially in situations with high variability of demand, relatively high explanatory power on the upstream side of the supply chain and a low correlation of individual forecast information, information sharing tends to yield strong benefits (Mishra et al. 2009, p. 163). These results are especially interesting because the make-to-stock scenario with a manufacturer and a retailer has many similarities to a scenario in which a service provider and his customer have to deal with uncertain end customer demand, without the ability to create safety stocks.

Besides these model-based results there is also some research based on case studies examining different implementations of CF in practice. Småros (2007) analyses collaborations between a retailer and four of his suppliers in the European grocery sector while McCarthy and Golicic (2002) gain their insights from case studies with an international chemical company, a consumer goods company and a manufacturer and marketer of basic apparel.

The four collaborations in the grocery sector differed strongly in the forms of collaboration and in their success. In the first case, the collaboration should be implemented in a modified CPFR process including the innovation of central demand forecasting with the aim to improve store-level forecast accuracy and replenishment efficiency. This aim was missed in the pilot phase because the companies were not able to break down the chain level forecast into store-level forecasts, not only because there was no investment in advanced IT. In the second case, the retailer shared his promotion plans with the manufacturer. The main benefits in this approach were the possibilities of better or similar forecasting results while lowering the dependency on the key account manager. In the third case the manufacturer got access to the POS data of new products. That enabled him to quickly identify stock-out risks and overly optimistic forecasts resulting in lower inventories and a 2.6% increase in the service-level. The partner in the last case also got access to the POS data, but could make no use of it, because the internal production intervals were too long, thus a timely reaction upon the changed forecasts was not possible.

McCarthy and Golicic (2002) extract the following main benefits from their studies:

- Increased responsiveness,
- Product availability insurance,
- Optimized inventory and associated costs,
- Increased revenues and earnings.

Supplier's earlier access to POS data enabled him to be more responsive facing large fluctuations in demand for highly seasonal products, with that reducing obsolescence and stock-outs. Less stock-outs increase the service level which decreases the numbers of customers lost to a competitor and therefore additional spending to win them back can be avoided. For another company this proved particularly valuable in the responsive reaction to customer's needs during the introduction of a new product.

CF as a collaborative relationship is a way to provide long-term product availability assurance. This can become a competitive advantage especially in today's proactive procurement environment, where customers try to aggregate volumes by reducing their supplier base. One company from the case study could establish a position as single supplier after implementing CF together with a main customer.

The consumer goods manufacturer was able to completely eliminate safety stock for certain SKUs "[…] due to consistent and timely communication of demand fluctuation from their customer" (McCarthy, Golicic 2002, p. 448). Similarly, in the partnerships between the chemical company and their collaborating partners safety stocks were significantly reduced by offering direct shipments based on the results of CF.

The apparel manufacturer used the shorter lead times gained by CF to move the production offshore, in doing so the supply chain cost could be decreased. For the chemical company, which was chosen as preferred provider directly due to outcomes of CF, this resulted in increased revenues.

The form of the contractual structure together with the power balance within a collaborative relationship are supposed to have strong influence on its success (Kurtuluş et al. 2012, p. 3). Assuming that CF under some conditions can yield significant benefits for the supply chain, it can still fail due to incentive misalignments within the collaboration. Reasons for this can be divided in two categories:

- The collaboration is not profitable for at least one of the partners in spite of the positive results of the supply chain as a whole,
- One or more of the partners have incentives to manipulate their shared data in order to increase their individual profits.

Type of contract	Description
Wholesale-price	Generally not considered a coordinating contract, though commonly used in practice due to low administrative burden.
Buyback	Manufacturer pays the retailer a (partial) compensation for any leftover inventory at the end of the season. Coordinates[13] under the assumption of voluntary compliance.[14]
Revenue-sharing	The manufacturer receives a percentage of the retailer's revenue in addition to the normal charge per unit. Coordinates the supply chain and arbitrarily allocates its profit.
Quantity-flexibility	Manufacturer charges the retailer per unit and then compensates him for his losses on a contractually limited share of his unsold units. Channel coordination is only achieved through forced compliance.[15]
Sales-rebate	Supplier charges a certain amount per unit purchased but then gives the retailer a rebate per unit sold above a threshold. Does not coordinate the supply chain with voluntary compliance.
Quantity-discount	The per unit wholesale price is decreasing in the number of units ordered.

Table 3.2: Types of contract coordination.

Since the allocation of the benefits achieved through CF strongly varies with the supply chain configuration, in general it is necessary to complement the partnership with a benefit-sharing rule (Aviv 2007, p. 793). This rule or mechanism has to assure that all parties can profit by collaborating and are therefore incentivised to participate in CF. According to Cachon (2003),

[13] Coordination here refers to a simple one season Newsvendor Model with stochastic demand.

[14] Voluntary Compliance means that the supplier delivers the amount that maximizes his profit given the terms of the contract and with the retailer's order as an upper bound.

[15] Forced compliance means that the supplier never chooses to deliver less than the ordered quantity due to fear of the consequences.

a contract is said to coordinate a supply chain if under the rules of this contracts the set of optimal supply chain actions is a Nash equilibrium, i.e. no player should rationally deviate from these actions. The simplest form of a benefit-sharing approach is a fee paid by the one that profits most to his partner to get access to his information. More sophisticated methods are buyback contracts, revenue-sharing contracts, quantity-flexibility contracts, sales-rebate contracts and quantity-discount contracts which are briefly described in Table 3.2 and extensively examined in Cachon (2003). The mentioned contracts have in common that they coordinate by shifting the profits and risks between the contracting partners. They vary in their ability to coordinate different supply chain constellations and in their administrative costs.

Incentive misalignments of the second category distort the results of CF, thus significantly reduce the overall supply chain benefits. When for example just sharing forecast information, the retailer has an incentive to inflate his data to increase the safety stock on the supplier's side (Lee, Whang 2000, p. 8). In a CPFR scenario without any additional transfer payments, the retailer and supplier have incentives to inflate or deflate their forecasts (Deshpande, Schwarz 2006, p. 3). Deshpande and Schwarz (2006) develop a linear transfer-payment scheme for CF to tackle this issue.

3.1.2.5 Potential risks of the CF concept

As described in the previous subchapter, CF can result in significant benefits, although there are as well certain risks attached which require thorough consideration. Risks in the context of CF can be divided in two categories: on the one hand there are risks on the way to a successful implementation of CF which concern mainly the managerial challenges of the required change processes; on the other hand there are risks which come from collaborating and rather affect the relationship between the collaborating partners. However, this categorization is not strict since any risk within the collaboration might be anticipated by one of the players and as a consequence repels him from joining in the first place if the trade-off between potential benefits and the expected risks turns out that way.

According to Barrat (2004) and Småros (2007) main general risks for a successful implementation can be listed as follows:

- Underestimation of the complexity of the required processes and over-reliance on technology,
- Lack of senior management support and commitment,
- Lack of internal integration and inflexibility,
- Differing expectations.

CF requires the participation of many different functional divisions from the participating companies (Barratt 2004, p. 38). Some of them might not have been involved with any forecasting processes at all while others might have to strongly adapt their processes. Even though highly sophisticated software might be used to support CF, it still requires the integration of this tool in the forecasting process. An over-reliance on technology and a underestimation of the complexity of the processes that have to be set up or adjusted can cause a significant increase of time and costs for the implementation of CF or even its complete failure (Barratt 2004, p. 30).

Another risk that also has to do with the need for coordination of many different players is a potential lack of top management support. Without the backing from senior management the functional friction might interfere efficient CF (Barratt 2004, p. 33). Acceptance of one single forecast as the basis for all further operations all over the supply chain is crucial for successful CF. Although particular units might disagree with this forecast, their acceptance has to be assured, which lies in the responsibility of higher management (Helms et al. 2000,

p. 402). Additionally, if collaborative processes are only implemented on an operational level and not integrated on tactical and strategic levels, which might happen without senior management support the benefits will stay limited (Barratt 2004, p. 33).

A lack of internal integration, i.e. the absence of integrated processes is a main obstacle to a successful implementation of CF (Barratt 2004, p. 32). If the processes in one of the collaborating companies aren't aligned to work efficiently with a single forecast, the main benefits of CF will be lost. If the supply side isn't flexible enough, they can't use the better information obtained through CF (Småros 2007, p. 714). Therefore it is important that CF is supported by additional agility improvements (Aviv 2007, p. 788).

Because of different planning horizons and aggregation levels the collaborating partners from successive supply chain levels might have different forecasting and collaboration needs (Småros 2007, p. 714). If this results in different expectations towards the result of CF, and if these expectations aren't aligned on time, at least one partner will be disappointed, and might consider stopping further collaboration.

According to Aviv (2007), Cachon and Lariviere (2001), McCarthy and Golicic (2002), Deshpande and Schwarz (2006), Småros (2007) and Li (2002) the main risks which may arise from sharing information between collaborating partners can be listed as follows:

- Information leakage,
- Opportunistic actions (manipulation, abusing),
- Low data quality.

The risk that some of the shared information leak into the hands of a third party which might be able to gain competitive advantage from it, is probably one of the biggest issues for many companies considering CF (Deshpande, Schwarz 2006, p. 2). In case of open data sharing between the partner it is just a matter of trust. Trust in the reliability of each other and trust in the rationality, i.e. that, as long as the partnership is profitable for all collaborating parties, neither would risk these benefits by upsetting the partner through information leakage, be it intentional or by accident. If CF is implemented as a secure protocol there still is a risk that data might be revealed from its results through inverse optimization as described in Pibernik et al. (2011) or though the dishonest behavior of colluding or malicious players as described by Atallah et al. (2004). Competitors could as well try to deduce information from the observable behavior of the collaborating partners. This problem is called indirect information leakage (Li 2002, p. 1197).

Another risk which increases inversely proportional with the quality of the implemented incentive schemes are opportunistic actions by one or more collaborating partners, e.g. inflation of an individual forecast to gain additional short-term benefits at cost of overall supply chain performance (Cachon, Lariviere 2001, p. 629). One of the player might as well abuse the obtained information to strengthen his bargaining position (Atallah et al. 2004, p. 2)

The required data has to be provided in a timely manner, on a high or at least well known level of accuracy and as detailed as necessary (McCarthy, Golicic 2002, p. 434). If this is not achieved by one or more of the partners and if it is not considered in the further process the result of CF might be distorted. For a company with rather low forecasting capabilities it might be reasonable to veil this weakness to get into collaboration, thus exploiting the partner's expertise.

3.1.3 Collaborative planning and monitoring – Vendor Managed Inventory[16]

This chapter focuses on collaborative planning and monitoring, especially the Vendor Managed Inventory (VMI) concept. The VMI concept will be explained and compared to the traditional replenishment process. If companies have the intention to establish a VMI partnership, they have to take into account several aspects. Therefore, in subchapter 3.1.3.3 various decision variables are presented, whose arrangement possibilities lead to different designs of VMI. The following subchapter 3.1.3.4 deals with the exchange of information, which is a key aspect of VMI. Finally, the benefits and risks of VMI are revealed.

3.1.3.1 VMI in contrast to the traditional replenishment process

The collaboration concept of Vendor Managed Inventory describes a partnership between a vendor and a customer focusing on inventory management. In research papers the transfer of stock management from customer to vendor is widely seen as the core element of VMI (Govindan (2013), p. 3808; Elvander et al. (2007), p. 782; Disney and Towill (2003b), p. 636; Dong et al. (2007), p. 355; Kaipia et al. (2002), p. 18). Hence, the vendor assumes the responsibility for replenishment of supplies and takes his own decisions on delivery date and quantities. The transmission of the vendor's sales data, stock levels and marketing activities enables the vendor to accomplish provisions reliably (Govindan (2013), p. 3808; Claassen et al. (2008), p. 407).

The main difference between VMI and the traditional replenishment process is the ordering process. Usually, the replenishment process is characterized by an order placement initiated by the customer. Based on his sales, forecast, production and/or inventory policies the customer determines his demand and places an order. Hence, the ordering data is the only information the vendor receives from the customer for planning his production and delivery activities (Disney and Towill (2003b), p. 629f).

In contrast to the traditional replenishment process, the order placement by a customer is completely eliminated in a VMI partnership (Kaipia et al. (2002), p. 17). A more comprehensive exchange of information as in the traditional replenishment process should empower the vendor to manage the customer's inventory on his own. The better insight into the customer's needs lowers the uncertainty in demand and enables the vendor to smooth his production and distribution activities (Waller et al. (1999), p. 184). Reduced costs and an improved service level are merely some of the benefits resulting from VMI that are suggested in research and will be reviewed in more detail in subchapter 3.1.3.4 (Waller et al. (1999), p. 184ff).

To illustrate the differences of the traditional replenishment process and the VMI concept, both concepts are depicted in Figure 3.2.

[16] This chapter was prepared in collaboration between the UWUERZ team, Julian Kurz and Richard Pibernik, with A. v. Riegen, R. Lorenz and J. Hornung

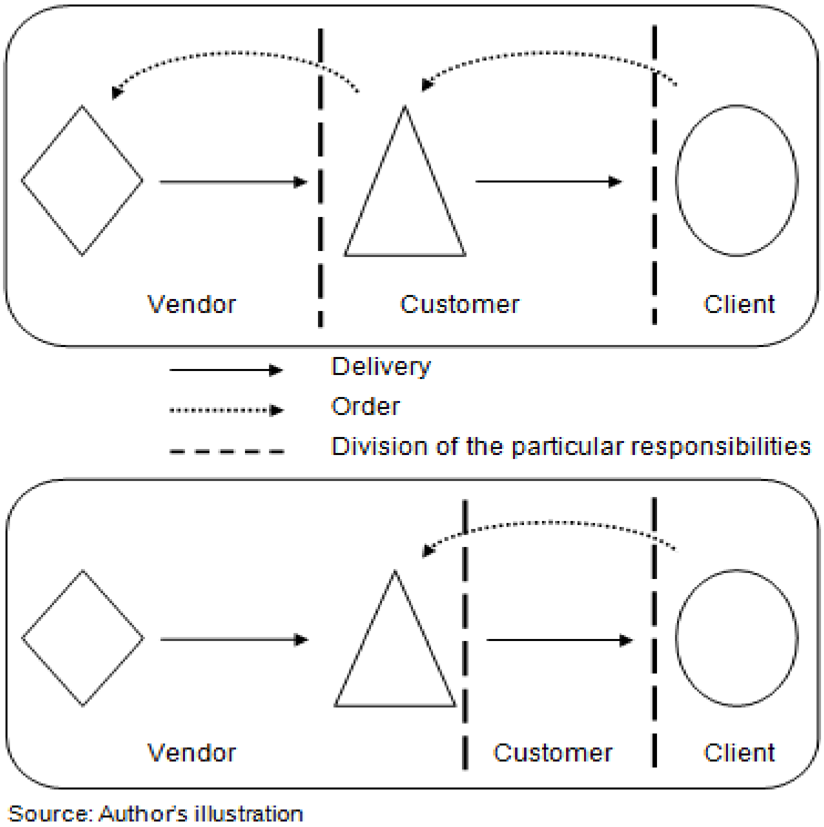
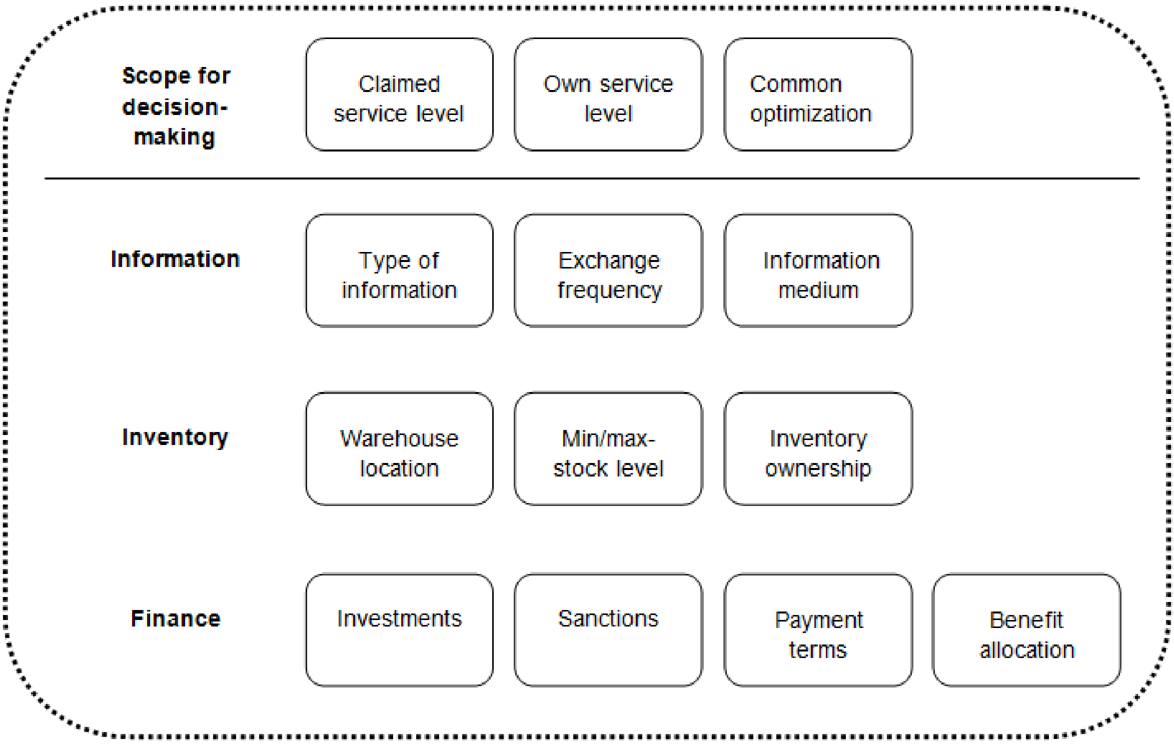


Figure 3.2: Traditional and VMI replenishment process.

3.1.3.2 Important decision variables in the VMI context

In contractual negotiations on the elaboration of a VMI concept, several important factors have to be taken into account by the involved parties. Initially, the parties need to agree on the extent of scope for decision-making the vendor shall be granted. Depending on the extent, different variants of the VMI concept may be distinguished. If the customer requires the strict fulfillment of a certain service level, the scope for decision-making is relatively limited (Waller et al. (1999), p. 183). If the vendor, however, is allowed to determine an optimized service level based on his own company activities, his scope for decision-making is much more comprehensive. A third variant is the joint optimization by both the vendor and the customer. Based on a mutual exchange of information, the common optimum solution is to be found. Therefore, the third variant has a more collaborative character than the other two alternatives mentioned before.

Beside the scope for the vendor´s decision-making, there are three more categories that are part of the contractual negotiations: information, inventory and financial aspects. These categories are divided into three or four decision variables, whose arrangements lead to an individual design of the VMI concept between the partners. In Figure 3.3 the different categories and their respective decision variables are shown.



Source: Author's illustration

Figure 3.3: Categories and decision variables in a VMI context

Regarding the information, the vendor and the customer have to decide which types of information will be exchanged. Due to the importance of this aspect in the VMI context, it will be further examined in subchapter 3.1.3.3. Furthermore, the parties need to agree on the frequency of the information exchange and a suitable medium for sharing of information (Vigtil (2007), p. 141ff; Elvander et al. (2007), p. 790f).

Concerning the category inventory, the warehouse location has to be determined by the parties. In a VMI collaboration the inventory is often stored in the customer's warehouse. Additionally, the vendor himself might keep sufficient products in stock to manage times of high customer demand. If the logistics division has been outsourced by the customer, the delivery of goods takes place at the third-party vendor instead of at the customer's location. If the customer is a producer, a product shipment directly to the manufacturing location is also possible (Elvander et al. (2007), p. 789).

Instead of defining a specific service level, the parties can also agree on minimum and maximum stock levels. The vendor may not exceed or fall below these levels. Depending on the extent of scope for decision-making, it can be agreed on either a maximum or a minimum stock level. Another alternative is the stipulation of a range arising from both a maximum and a minimum limit (Elvander et al. (2007), p. 789).

The third decision variable concerns the ownership structure regarding the inventory, i.e. the customer and the vendor have to agree on the time of the transfer of property. One possibility is the arrival of the delivery of goods at the warehouse representing the moment of transferring the ownership. Another alternative is an agreement on consignment stock, which provides the customer obtaining property as recently as he removes goods from his warehouse (Govindan (2013), p. 3818; Holweg et al. (2005), p. 174; Elvander et al. (2007), p. 789f). Actually, consignment and VMI are two distinct inventory concepts with the possibility of combination.

The category finance includes four decision variables. Decisions have to be made concerning investments, sanctions, payment terms and the benefit allocation. VMI is potentially accompanied with high initial investments which occur, among others, due to the alignment of IT infrastructures of both parties. It is therefore necessary to stipulate which expenses incur and how the costs will be allocated between the customer and vendor. Furthermore, the contract should provide penalties for breach of contract, for example for non-fulfillment of the service level by the vendor.

The payment terms are usually based on the time of delivery. To prevent discrepancies afterwards, the procedures of payment should be specified in the contract documents. Without the existence of potential benefits the implementation of VMI would not be considered by either party. To what extent these benefits and the realized profits are allocated later between the customer and the vendor has to be agreed on and documented.

Between several decision variables interdependencies can be stated. It thus stands to reason that the extent of scope for decision-making influences the amount of exchanged information. The greater the autonomy in decision-making regarding delivery date and quantities and the stronger the collaboration the more comprehensive the exchange of information should be to implement the VMI concept efficiently. A strong partnership can also imply a higher willingness to inform partners regularly about the current situation resulting in a higher frequency of information exchange. Furthermore, the commitment to technology investment may have a favorable effect on the exchange of information because the parties may choose a high-quality system due to a larger budget.

Thus, many aspects have to be considered by the parties while negotiating the establishment of a VMI partnership. Depending on the agreements concerning the particular decision variables, different designs of VMI may be developed. Therefore, it is possible to state that there does not exist one typical design of the VMI concept, but many individual variants.

3.1.3.3 Information exchange

An effective information exchange is considered to be a core element for a successful VMI cooperation. Therefore, a closer look on this aspect is mandatory. In VMI, the information flow is reciprocal, i.e. there is a two-way communication with two or more partners and multiple information flows (Liu and Kumar (2009), p. 732). According to Caridi et al. (2014), the shared data typically consist of several types of information, with one example each:

- Transactions/Events: Data related to an event which takes place, e.g. shipping notes,
- Status information: Data that describe the status of resources or processes, e.g. inventory levels,
- Master data: Data related to product features, e.g. component features,
- Operational plans: Data about future plans, e.g. delivery plans.

Further occurrence of these four types in a VMI cooperation are discussed later on.

In the following section it is in some cases important to distinguish between the two phrases ‘information’ and ‘data’. Data are exact numerical or alphabetical single values which are generated, transported and stored for a particular purpose. Structured data are called information. Whereas data are the medium to contain information, those deliver the actual message. This message however must imply news for the recipient otherwise the data do not deliver information. So the same data could provide different information to different recipients (Thome (2006), p. 52f).

Types of information – a literature-based overview

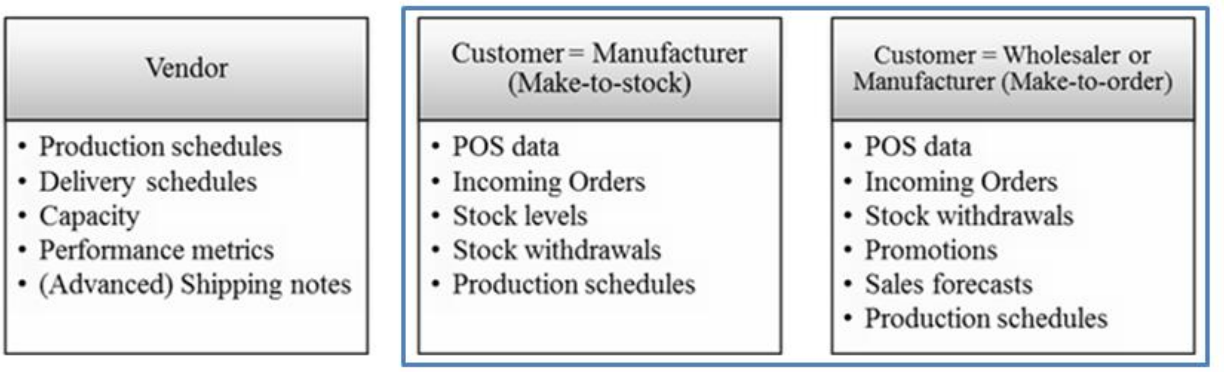
It is inexplicit which exact forms of data as regards content should or even could be shared in a VMI cooperation. Vigtil (2007) assembled the information from a literature review pointing out that most authors suggest to share a variety of data. Other authors come to similar results in their studies. In the following, a short overview about most frequently mentioned types of information is given.

On one hand, a customer should share data with his vendor that are associated with the sales process. Most important in this category are the so called point-of-sale (POS) data. These are data typically registered by an electronic checkout system and include information about price of goods sold, amount, time or even an identified consumer. Together with sales data, it is often suggested to also share incoming orders because they influence future sales directly. Besides, it is proposed to share stock levels and stock withdrawals. These data can often be deduced from sales data or are elevated separately. If they are deduced from sales data they must be checked towards correctness periodically, because dwindling and loss are often not noticed elsewise. The function of this data is mainly to manage the inventory within certain guidelines.

On the other hand, the customer should share data that affects his sales in future indirectly like planned promotions or knowledge about market trends and consumer wishes merged to a sales forecast. If the customer further processes the delivered goods, information about production schedules are often useful and aiming to increase production plan adherence, but could also eventually limit the freedom of choice of the company.

The vendor is normally expected to share his production and delivery schedules, his capacity and performance metrics like product quality, lead times or queuing delays at workstations. The vendor should also provide an advanced shipping note with the purpose of as well preparing the customer of an impending delivery as tracking and tracing this shipment (Vigtil (2007), p. 134ff; Hung et al. (2014), p. 54ff; Lee and Whang (2000)).

To illustrate the different types of information, they are depicted in Figure 3.4.



Source: Author's illustration

Figure 3.4: Shared data in VMI cooperation according to different participants

One has to bear in mind that those data are expected to be shared within the VMI partnership continuously. But there is also information that is shared once and even before a contract is concluded. Both forms will be analyzed in the following chapters. Both cases, one-time exchange and continuous information exchange, have in common that it is aimed to serve the partners with more and more accurate data to reduce uncertainty in the negotiation or the replenishment process (Alicke (2005), p. 173). Information sharing reduces for example the uncertainty regarding the well-known bullwhip effect. This beneficial aspect will be revisited later on. Studies show that the most important factor to foster information sharing is trust between the participating companies. Consequently, a lack of trust is the main reason for impeding the willingness of sharing information (Hung et al. (2014), p. 54ff; Marquès et al. (2010), p. 552).

One-time exchange of information before contract formation

To decide if a VMI partnership should be established, it is necessary to elaborate the potential financial benefits of introducing such a system. To calculate these benefits and in order to share them adequately to the risks and efforts of the involved companies, information must typically be disclosed. In literature, there does not exist an adequate and complete list of elements which should be considered by those calculations. Eventually, an academic void reveals itself here. Yao et. al. (2007) point out that ordering costs and carrying charges should be externalized because those affect the inventory cost savings which could be shared between vendor and customer. The greater the reduction of order cost for the supplier through VMI compared to his cost prior to VMI the larger are total benefits (Yao et al. (2007b), p. 671). One could further assume that more cost influence those total benefits and thus more information should be shared in order to assess the advantageousness of VMI. The vendor must also indicate his production and his complete transportation cost as well as his actual production capacity. Both should share their storage cost, administration cost and sales margin. The customer should externalize his overage and underage in addition. Especially, to disclose such kind of information in advance of deciding if VMI actually makes sense, is often a major drawback for companies to agree to collaboration obviously. Companies in general show a lack of willingness to share sensitive data because of concerns about their confidentiality (Hung et al. (2014), p. 48ff). Considering such data, a company gains huge insights into another company which increases the risk of an opportunistic behavior when a company could try to misuse the information learned. This and other risks will be revisited in section 3.1.3.6.

Continuous exchange of information after contract formation

The sequence of activities in a running VMI replenishment process consists of several independent, but sequential steps where in each step different data are exchanged. It is obvious that, depending on the deepness of the coordination and on the specification of the disposed VMI relationship as addressed before, more or less data must be exchanged continuously. The purpose of continuous information exchange is to achieve convergence between each partner’s perspectives and levels of knowledge (Marquès et al. (2010), p. 556). In the following section some general steps which cover the replenishment process in a two-partner VMI partnership are highlighted.

First of all, the customer shares his actual demand or usage with the vendor in which it is not inevitable that he performs this task actively (1). The demand is evaluated by the customer from his commercial knowledge like seasonal variation, from sales or inventory data or from a sales forecast which is often also deduced from previous sales. If required additional information like win or loss of large consumer, planned promotions or large unique sales are shared also. The vendor handles these information and takes actual steps to satisfy the demand. Usually, a demand forecast is generated or at least updated and a replenishment order is placed in the production system and scheduled. Depending on how well-rehearsed the process is, the customer reviews and confirms the replenishment order or not (2). Eventually, the vendor does not responds to the customers demand before production and collocation of the goods needed. Hence, he sends an advanced shipping note (ASN) and then provides the physical goods (3). Upon receipt the customer acknowledges (4) and uses the goods or sends them back if they eventually do not meet his demand or his quality expectations. This should naturally not happen as a rule. But when it comes to a deviation from the common process flow or performance prospect, some kind of exception handling must enchase and inform the effected partners (Liu and Kumar (2009), p. 732f; Alicke

(2005), p. 174; Waller et al. (1999), p. 183). To illustrate this process, it is depicted in Figure 3.5.

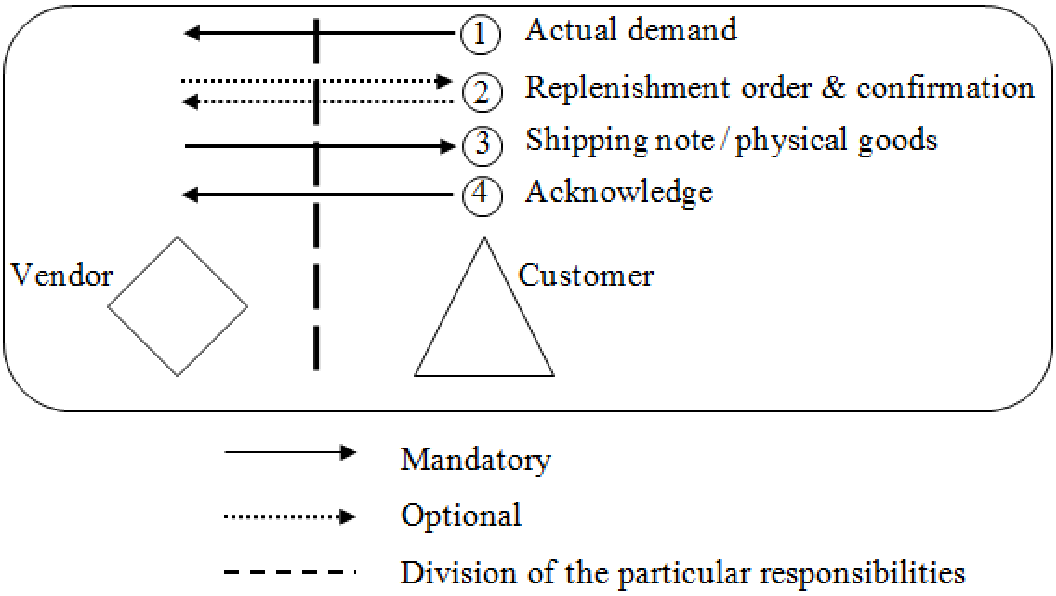


Figure 3.5: The VMI replenishment process (Source: Author's illustration)

In the concluding two sections of this subchapter, quality requirements regarding the shared data and technological properties are introduced.

Requirements for information exchange

Nowadays, it is appropriate to assume that nearly every larger company uses advanced information systems for the fulfillment of its daily tasks. In this approach, data transmission is performed electronically with minimized transfer time and reduced entry and transmission mistakes (Simchi-Levi et al. (2009), p. 254f). Exchanged data are expected to fulfill at least some of the further quality criteria which are introduced shortly in the following passage.

- **Accuracy**: Data are free from errors and are not distorted while the transmission (Mohr and Sohi (1995), p. 409; Closs et al. (1997), p. 8ff).
- **Availability**: Data can be accessed when and where desirable. This is achievable in best shape when data (e.g. POS data) are updated real-time or at least are transmitted in a batch with periodic updates (Vigtil (2007), p. 134; Alicke (2005), p. 174; Closs et al. (1997), p. 8ff; Angulo et al. (2004), p. 112).
- **Completeness**: Data include both required and available information allowing to perform appropriate for the partner (Angulo et al. (2004), p. 102).
- **Relevance**: Data contain information and create a surplus for the recipient. With this data he is able perform the expected tasks (Caridi et al. (2014), p. 2ff).
- **Reliability**: Data reflect the actual circumstances and allow to make correct decisions (Angulo et al. (2004), p. 102).
- **Usability**: Data do not need to be entered manually or transformed with much effort, but can be used instantly (Kaipia and Hartiala (2006), p. 10ff).

The existence of suitable technologies which are able to facilitate the adherence of those properties is important.

Technological properties

As emphasized before, a close information exchange is important to integrate and coordinate operations between vendors and their customers (Yao et al. (2007b), p. 663f). Every piece of data or information needs a medium to enable transferring, storing and editing. Modern media are newspapers, televisions and of course single computers or whole information systems (Thome (2006), p. 53). Obviously, this is a broad range of different media where some are suited better for the VMI information exchange than others. Sometimes it is challenging to explore proper medium and process to transmission. To foster cooperation and the success of a VMI intention, first and foremost stable and reliable media which connect the companies are essential. But this fact does not imply that an elaborate and hence costly information system is necessary as a matter of course, because most information sharing practices consist of basic level transactions and thus occupy simple media comparatively (Hung et al. (2014), p. 48ff).

Different technologies are in charge depending on the purpose: share numerical data or perform strategic thinking.

- Networking with EDI (electronic data interchange): Either the data objects in XML-based, specified shape are shared between certain information systems or the partner has online access to the information system and can check through it itself. This form is suitable for all four types of information (Waller et al. (1999), p. 187ff; Liu and Kumar (2009), p. 735f; Hung et al. (2014), p. 54).
- Email: Information is simply shared within text messages. One major drawback with this procedure is that the information needs to be extracted by a person usually before subsequent use (Hung et al. (2014), p. 54).
- Videoconference/Telephone: Information is shared face-to-face or within voice transmission. This form is most likely suitable for operational plans, for the other three types rather not (Hung et al. (2014), p. 54).
- ERP (Enterprise Resource Planning) – Systems: The ERP systems of cooperating companies are connected in such shape that the information systems itself share the agreed data automatically in case of changes or periodically. This is mostly suitable for master data, transaction data and status information as well (Kelle and Akbulut (2005), p. 41ff).
- RFID (Radio Frequency Identification): This is a special case towards EDI where the data is recorded and transmitted automatically using scanners which are able receive radio waves emitted from the products. This procedure aims to improve VMI efficiency and reduce manual effort (Yao et al. (2007a), p. 133ff; Delen et al. (2007), p. 613ff).

In the concluding section of this chapter follows, as announced before, a reflection on the advantageousness of VMI and potential risks of the concept.

3.1.3.4 Benefits of VMI

The benefits of VMI and in particular for the respective participants are divergently discussed in literature (Bookbinder et al. (2010), p. 5550; Dong and Xu (2002), p. 76; Yao et al. (2010), p. 350). There are research papers, proclaiming advantages for both participants (Achabal et al. (2000), p. 433; Claassen et al. (2008), p. 406f; Waller et al. (1999), p. 184ff) while some question the advantageousness for the vendor (Dong and Xu (2002), p. 76ff; Yao et al.

(2007), p. 664ff; Vergin and Barr (1999), p. 149) or attribute the main benefits to the vendor (Xu et al. (2001), p. 46). Similarly, the findings concerning the benefits' magnitude are diverse. For example, the empirical study of Vergin and Barr shows reduction of inventory levels from 20% to 50% (Vergin and Barr (1999), p. 149). These findings can be explained to some extent due to influencing factors and different implementations of the VMI concept.

In the following subchapters, the potential benefits of VMI and its influencing factors will be discussed. Depending on the interpretation of VMI, some researchers also number consignment stock to VMI (Dong and Xu (2002), p. 75ff; Yu et al. (2009), p. 274). By definition in subchapter 3.1.3.2, consignment stock and VMI are two distinct inventory strategies which may be combined. Therefore, aspects of consignment stock will not be addressed in this subchapter. Interested readers in its effects and challenges are directed to Govindan and the herein referenced literature (Govindan (2013), p. 3818f).

Potential Benefits of VMI

Potential benefits of VMI get in the following attributed to the categories *(1) improvement in transparency, (2) improvement in transaction process* and *(3) improvement in customer service*.

(1) Improvement in transparency. The most important benefits of VMI can be achieved due to increased transparency and demand visibility (Vigtil (2007), p. 133). The traditional supply chain is characterized by non-transparency. The vendor usually has a very short time frame to react to customer orders. Without insights into customers' actual inventory levels as well as demand at their locations, it is difficult for the vendor to anticipate prospective orders and synchronise his production in accordance with those. In case of several and almost simultaneously arriving orders by different customers, the vendor gets under pressure to fulfil these orders within time (Kaipia et al. (2002), p. 18). In addition, an anticipation of product shortage by the customer might lead to rationing gaming. As a consequence, the non-transparency for the vendor increases and a bullwhip effect results (Lee et al. (1997), p. 556; Achabal et al. (2000), p. 433). To avoid stockouts as well as poor service levels, vendors use the costly solution of holding excess inventory and production capacity (Holweg et al. (2005), p. 171; Disney and Towill (2003b), p. 630ff; Waller et al. (1999), p. 184). Nevertheless, stockouts occur causing stockout costs as well as penalty costs (Waller et al. (1999), p. 185).

In VMI collaborations, data transfer such as POS data, inventory data and information about promotional activities increase visibility in supply chains. It gives the vendor a more accurate view on demand (Waller et al. (1999), p. 186). The transparency leads to a reduction of the bullwhip effect (Disney and Towill (2003b), p. 647; Lee et al. (1997), p. 558), commonly halving it (Disney and Towill (2003a), p. 212). Additionally, the vendor gains flexibility to smoothen peaks and valleys in the ordering process. If there are more customers connected with VMI to the him, he might coordinate deliveries to different customers according to the their respective urgency. As a result, the vendor is able to abolish excess inventory and capacity while keeping stockouts low (Waller et al. (1999), p. 184ff). Owing to the longer planning horizon and better insights into demand patterns, he can set production schedules which consider desired service and inventory levels as well as set-up costs (Waller et al. (1999), p. 185; Lee and Whang (2000), p. 378ff). In addition, transparency is the basis for other benefits which are described in the following section.

(2) Improvement in transaction process. VMI is proclaimed to enable vendors under specific conditions to improve the systems forecasting accuracy (Blatherwick (1998), p. 10; Achabal et al. (2000), p. 431). Those conditions are forecasting skills and transparency especially about promotional activities (Dong et al. (2007), p. 356). Vendors are said to have a more limited product range. Therefore, they might be able to build more specific knowledge about the products and have a better focus on them. (Vergin and Barr (1999), p. 147; Claassen et al. (2008), p. 407). Additionally, if vendors get POS data as well as information about

promotions by different customers they have a wider information basis about demand patterns. This may result in better forecasting, thereby reducing safety stock and inventory levels (Xu et al. (2001), p. 46). At the same time, VMI leads to higher replenishment frequencies (Waller et al. (1999), p. 184) and as a consequence, faster inventory turnovers (Achabal et al. (2000), p. 432). This reduces inventory and its costs even more. In accordance with that, a bigger range of products can be stored on the same or nearly the same shelf space (Angulo et al. (2004), p. 114; Achabal et al. (2000), p. 430).

While in traditional supply chains, both partners deal with the ordering process, in VMI only one partner is truly involved in replenishment decisions (Disney and Towill (2003a), p. 200). By bundling inventory management decisions, the vendor may exploit economies of scale (Çetinkaya and Lee (2000), p. 218; Achabal et al. (2000), p. 433). He might be able to simplify and automate the ordering process (Alicke (2005), p. 175). By planning delivery routes and combining replenishments at different customer locations, the vendor improves the utilization of truck loads and therefore lowers transportation costs (Waller et al. (1999), p. 185f; Campbell and Savelsbergh (2004)).

Due to the eliminated ordering processes, the customer can focus on his core competencies and save administrative costs (Vergin and Barr (1999), p. 147; Claassen et al. (2008), p. 406). The efficient implementation of VMI makes the application of information technology necessary. This reduces order processing costs (Cachon and Fisher (2000), p. 1044f).

Moreover, VMI helps to reduce the number of emergency and incorrect orders (Claassen et al. (2008), p. 409; Kaipia et al. (2002), p. 18).

Another benefit of VMI is a closer vendor-customer relationship (Achabal et al. (2000), p. 432). Successful VMI can be the foundation of customer loyalty and a long trustworthy relationship which may affect other business fields as well. On the other hand, VMI results in mutual dependency which is a double-edged benefit. For the vendor it is a chance to tie the customer to himself and thereby secure sales but it may also be a reason not to commit to VMI for the customer (Vergin and Barr (1999), p. 152; Xu et al. (2001), p. 46; Clark and Hammond (1997), p. 264).

In addition, VMI helps to overcome conflicting performance measures of the customers' purchaser which result in suboptimal ordering strategies for the system (Waller et al. (1999), p. 184).

(3) Improvement of customer service. The benefits due to customer service improvements are of financial as well as of non-financial nature.

Financial benefits can be rooted to an increase of product sales. As a result of better resource utilization, cost savings can be handed down to the consumer in form of lower selling prices. This leads to higher demand and increased product sales especially for items with high price sensitivity (Dong and Xu (2002), p. 84; Vergin and Barr (1999), p. 149).

Improved forecasting and delivery plans lead to better product availability and result in an increased number of products sold as well as higher customer service levels (Waller et al. (1999), p. 185f). Due to a reduction of the order lead time (Cachon and Fisher (2000), p. 1046), the process of VMI is faster and therefore provides a higher customer service.

Beyond that, the set target service level of the customer in the traditional replenishment process might not be optimal for the vendor or the whole supply chain (Lee and Chu (2005), p. 160). The optimal inventory level is partly determined according to stockout costs. Owing to a different cost structure, the vendor might be interested in higher target service levels than the customer. This might be motivated on the one hand by a higher profit margin. On the other hand, the vendors' stockout costs might be higher than the customers'. For example, in case of stockouts in the grocery industry, consumers may switch to substitute product. While this ensures the sale for the retailer, the sale for the vendor is lost. In case of satisfaction with the substitute, the vendor might permanently lose the consumer to another brand. Owing to these negative effects of stockout situations, the vendor might target higher service levels than the retailer to strengthen his competitive situation and ensure product sales (Kraiselburd et al. (2004), p. 46) . The revenue of the whole supply chain could be maximized if the vendor knew all relevant costs of both parties. He could determine the collaborative service level which maximizes the revenue for both (Claassen et al. (2008), p. 407). Because of the sensitiveness of cost information, this information exchange is a risk for firms and therefore will be approached in the next chapter.

3.1.3.5 Influencing factors and challenges of VMI

This subchapter addresses factors which influence the outcome of VMI. The *aspects (1) relationship, (2) ability of the vendor, (3) duration, (4) information flow* and *(5) environment of implementation* have an impact of the realized extent of benefits. This chapter elaborates those aspects and regards challenges of an implementation.

(1) Relationship. Practitioners and scientific literature emphasize the role of trust in VMI collaborations (Claassen et al. (2008), p. 408ff; Pohlen and Goldsby (2003), p. 569f). Trust is a complex human construct. Its different aspects come into effect in VMI. One aspect is trust in the partner’s competence to deal with the tasks evolving from VMI (Cheikhrouhou et al. (2013), p. 88ff). Compared to the traditional situation, the customer loses control of the replenishment process and gets dependent on the vendors ability to manage his inventory (Kaipia et al. (2002), p. 23). On the other hand, the vendor must trust the ability of the customer to provide accurate and correct data (Kulp (2002), p. 655). This kind of trust is referred to as competence trust in literature. Competence trust is the foundation of collaboration. Without it, companies would not agree to become dependent in collaboration from each other. Besides competence trust, trust in the partner’s honesty as well as loyalty and confidentiality play important roles (Cheikhrouhou et al. (2013), p. 89f). In VMI arrangements, a wide scope of decision making leaves the vendor with the opportunity to act self-interested and opportunistic. For example, if the customer bears the cost of inventory, the vendor has incentives to stock more inventory than needed. Companies are therefore reluctant in giving the vendor a wide scope of decision making (Yao et al. (2007), p. 672; Christopher and Jüttner (2000), p. 119; Vigtil (2003), p. 68).

Another issue of trust is the exchange of sensitive information. Companies fear leakage of sensitive information because of opportunistic behaviour on the one hand or security lacks on the other hand (Lau, Jason Shiu Kong (2007), p. 88f; Kuk (2004), p. 653). This concern increases if the shared data contains cost information. Therefore, cost-related information is rarely exchanged between two independent parties (Bookbinder et al. (2010), p. 5552) making it difficult to obtain decisions which optimize supply chain costs.

Companies try to reduce the role of trust by using contractual arrangements which limit the scope of decision making and the opportunity of self-interested behaviour of the partner. For example, customers make use of tight upper and lower inventory levels. Combined with high penalty costs in case of aberration, the vendors’ scope of decision making gets significantly reduced. As a consequence, the vendor has a shorter planning horizon and less freedom to decide about delivery schedules. These arrangements might indeed reduce the risk for the buying firm. On the downside, too tight constraints contradict the idea of VMI and prune its potential benefits (Claassen et al. (2008), p. 408ff). Hence, the challenge is on the one hand to find measures to reduce the role of trust via incentive structures, performance measures and contractual arrangements and on the other hand to build trust to facilitate dealing with the left over risk.

(2) Ability of the vendor. The advantageousness of VMI depends highly on the opportunity and capability of the vendor to extract benefits of his new tasks and information basis. First of all to improve his production and delivery plan, the vendor needs a significant portion of his total business covered by VMI. The threshold is estimated to be 30 – 40%. Many vendors

have not yet achieved this threshold (Vergin and Barr (1999), p. 151; Claassen et al. (2008), p. 408). The vendors goal is therefore to connect to more customers in VMI (Kaipia et al. (2002), p. 23). However, it could be shown that the volume of vendors' business handled by VMI was dependent on the time he was performing VMI. The longer he took part in a collaboration, the more products and other customers were covered (Vergin and Barr (1999), p. 149ff). On the downside, an increased number of collaborating partners exacerbates an integration of all information to the vendors business activities (Holweg et al. (2005), p. 171).

Additionally, the vendor's forecasting skills have an impact on the benefits of VMI (Aviv (2002), p. 56).

Analytical as well as empirical studies showed that in some cases, a reduction of the customer's inventory levels was only possible on the vendor's expenses. The vendors have to hold higher inventory levels because they were not able to use the potential benefits of VMI while their customers got stricter about occurring stockouts (Vergin and Barr (1999), p. 151; Yao et al. (2007), p. 672). As a result of unevenly distributed cost reductions, side payments may be required to gain a long and healthy relationship (Yao et al. (2007), p. 672). The height and conditions of side payments are another challenge.

(3) Duration. Another influencing factor for the success of VMI is its duration. Some benefits only appear after time as for example increased product sales. The same applies to the fundamental comprehension of VMI and its implementation. As illustrated in subchapter 3.1.3.2, there are different arrangements for VMI which each imply varying benefits. The challenge is to understand the concept as well as its enablers and to decide on this basis about the particular implementation (Rungtusanatham et al. (2007), p. 112; Vigtil (2003), p. viiif). The longer VMI is performed, the better understanding and benefits utilization is achieved. An iterative process sets in, self-energizing by positive experience and increased understanding of underlying processes and requirements (Vigtil and Dreyer (2008), p. 447f).

(4) Information flow. The type of information that should be transferred was already stated in chapter 3.1.3.3. Besides that, cross-functional and inter-organizational information flow is vital for VMI. To ensure communication between marketing and supply functions of the customer on the one side and the vendor's supply and production division on the other side, appropriate technology as well as cross-functional teams should be initiated (Claassen et al. (2008), p. 407; Stank et al. (2001), p. 40). Data transfer at specific times should become a routine to bestow planning certainty for the vendor (Vigtil (2003), p. viii).

To reduce administrative costs, information flow and the transaction process between customer and vendor should be as resource-poor as possible. Therefore, appropriate data interfaces have to be implemented as already discussed in subchapter 3.1.3.3. In practise, this seems to be challenging. A number of implemented processes are not fully connected and require transformation from one system to another (Elvander et al. (2007), p. 791). Thus, benefits of reduced administrative and process costs decrease owing to non-integration of those processes.

(5) Environment of implementation. The advantageousness of VMI is dependent of the environment in which it is introduced. Sari (2007) was the first one to emphasize the role of external partners. He examined the effect of low capacity of non-participating suppliers who provide items to a participating vendor. He found out that less capacity of those non-participating vendors had a negative effect on the benefits of VMI. This is of special importance in environments with high volatility (Sari (2007), p. 531ff).

As the benefits of VMI are measured as an improvement to the previous performance, the realized benefits are also dependent on former communication and purchasing strategies. The benefits of transparency for example only have an effect if the former ordering process was non-transparent and characterized by unsteady orders. If contrariwise, the vendor was able to roughly estimate the timing and amount of ordered items, the resulting transparency of VMI does not entail large benefits (Cachon and Fisher (2000), p. 1046).

Another influencing factor is the kind of product VMI is implemented for as well as its market characteristics. VMI can be beneficial for a wide range of products and demand patterns (Claassen et al. (2008), p. 408). Nevertheless, some products imply bigger benefits for the partners than others because of their characteristics. In research, these characteristics are just scarcely examined.

VMI has its origin in the grocery industry. In the 1980’s, VMI was successfully implemented by Wal-Mart and Procter & Gamble. The concept has then been adopted by different companies of the food industry, for example Campbell Soup and the pasta manufacturer Barilla (Waller et al. (1999), p. 183). In line with the origin of VMI, Ketzenberg and Ferguson could confirm that increased transparency and centralized control leads to fresher products. Therefore, VMI holds benefits especially for slow moving perishables (Ketzenberg and Ferguson (2008)). This holds for both, food and innovative consumer products with short life cycles, because the demand of those is unstable and therefore hard to predict. Besides, VMI is particularly useful for the producer of perishable goods if he is distant from the consumer market (Hung et al. (2014), p. 51).

Waller et al. state that benefits can be realized for products with low demand variability as well as products with high demand variability. Reductions in safety stocks can be achieved in both cases. The benefits emerge from reduced cycle and safety stocks (Waller et al. (1999), p. 190). The benefits’ magnitude for volatile products is higher if volatility is explicable and therefore can be forecasted (Aviv (2002), p. 56; Sari (2007), p. 542). Otherwise the benefits of VMI decrease and result primarily from longer reaction times due to actual POS data.

Seasonal products as well as temporary promotional goods seem not to be of special applicability for VMI. Due to their shorter life cycle and lower selling volume they hardly justify the effort of implementation and the investment costs (De Toni and Zamolo (2005), p. 56). However, if companies are already connected through a VMI partnership, then the implementation of seasonal products into the existing product portfolio is cheaper and therefore advantageous (Clark and Hammond (1997), p. 264). Old inventory in the system and associated “fire sales” could be prevented (Waller et al. (1999), p. 186). In addition, the vendor is able to make strategic decisions for other seasons based on the sold quantity of a specific product. In the apparel industry for example, purchase volume of the customer does not provide information to the vendor about markdowns or stockouts in midseason (Achabal et al. (2000), p. 433). Nevertheless, this information is useful for decisions concerning other seasons. Additionally, very responsive manufacturing vendors might even be capable to produce styles in accordance with actual selling quantities. Nevertheless, benefits of VMI usually decrease with more responsive vendors (Vigtil (2007), p. 146) because transparency bears less value for them.

Products which are characterized by high volume and of high value are advantageous for VMI implementations (Franke (2010), p. 24). This holds especially if those parts decrease in value within relatively short time frames. Owing to reduced inventory stocks and faster inventory turnover, capital commitment and loss over time sink. Moreover, the needed space to store the products decreases.

Different authors indicate to various companies and industries which implemented VMI, for example: electricity (De Toni and Zamolo (2005)), automotive (Niranjan et al. (2012), p. 947) and pharmaceutics (Niranjan et al. (2012), p. 945; Waller et al. (1999), p. 183) etc. An overview of case study domains can be found in Govindan (Govindan (2013), p. 3827).

3.2 Application to aerospace industry

3.2.1 Aero Engine overhaul planning

As said in the chapter 2, the aero engine MRO is the biggest segment in terms of profitability in the MRO market (see Figure 2.5). The aero engine overhaul supply chain is characterized by four main sources of supply to engine shops, as it is shown in Figure 3.6:

- *Material/Parts Suppliers* that include engine OEMs, PMA[17] holders and surplus dealers. They can sell directly to engine MRO service provider or through a distributor (surplus dealers tend to sell directly to engine overhaul shops).
- Distributors that buys from material/part supplier in order to sell to MRO service provider.
- *Repair/Specialty Service Supplier*s like engine OEMs and large airline third-party engine MRO service providers.
- *Labour* that is internal to the engine overhaul shop.

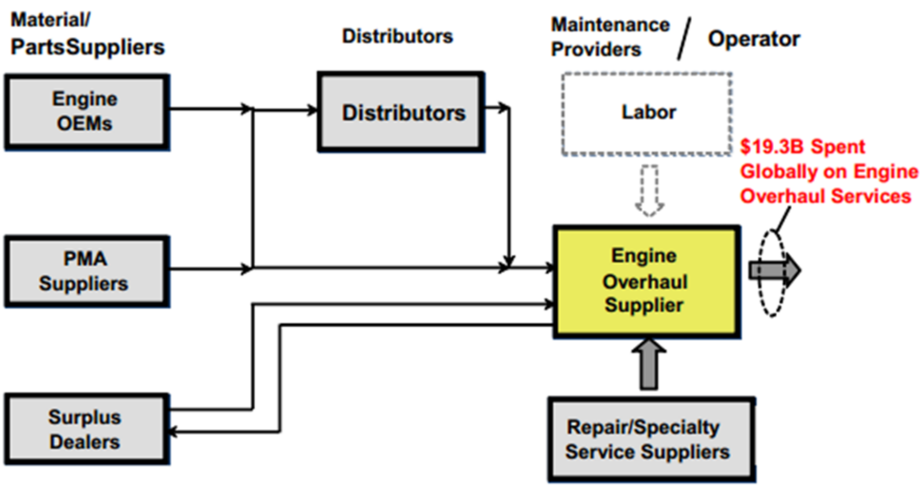


Figure 3.6: Engine overhaul supply chain. Source: Aerostategy (2009).

MRO service providers may provide engine maintenance services under two main types of contract: *time and material contracts* in which the customer is charged a posterior for a numbers of costs such as labour, materials, life limited parts (LLPs) and subcontracted work spent in the engine; *flight hour contracts*, where the customer is invoiced by a predetermined rate per flight hours[18].

Today, to be competitive in the global aero engine MRO industry, engine MROs have to use effective ICT applications in order to predict and schedule engine shop visits. In this way it should be possible to:

- Plan shop maintenance slots;
- Optimise materials provisioning;

[17] Parts Manufacturer Approval (PMA) is an approval granted by international certification authorities to a manufacturer of aircraft parts (Wikipedia, 2014).

[18] The ‘flight hour contracts’ is diffusing quite rapidly whenever having working fleet is very important for owner.

- Avoid aircraft on ground (AOG) due to lack of engine replacement (this is a very critical issue in the second type of contracts);
- Ensure adequate capacity by service providers for subcontracted work;
- Optimise engine time on the wing.

In the past, engines were removed and overhauled mandatory only after a fixed time interval, even if they operated safely and satisfactorily. Currently, engines are maintained on an on-condition monitoring basis (Ackert, 2011): they are removed only when an internal component reaches its individual life limit, or when engine is operating outside manufacturers suggested parameters. For this reason, regular measurements of the engine's operating speed, temperature, pressure, fuel flow and vibration levels are taken and tracked by special software, in order to monitor the engine performance, and to identify potential problems. To be precise, aero engines are subject to control by all the primary maintenance processes described in the paragraph 2.1.3. Hard Time maintenance, unlike the On-Condition one, allows a relatively easy planning of overhaul, especially when the aircraft are operated in accordance with the plan.

In On-Condition contract type a lot of data related to engine are stated periodically by the customer (the way to share data depends on technological infrastructure available to customers and service providers); the service provider, instead, based on data he has, decides which activities carry out. To explain better what On-Condition maintenance is, in the Table 3.3, Table 3.4 and Table 3.5 below data relating to engine status and technical condition considered during this type of maintenance are shown (Batalha, 2012).

Table 3.3: Engine status. Source: Batalha (2012)

Engine Model	**PW 4060** **Manufacturer: Pratt & Whitney**
Engine Serial Number	NNNNNN
Aircraft – Type	Boeing 767-300 ER
Registration	CS-XXX
Position Nr	2
Hours (Time) Since New (HSN or TSN)	51104
Cycles Since New (CSN)	10177
Date of Last Shop Visit (DLSV)	22JUN2005 Shop SRT
Hours Since Last Shop Visit (HSSV)	15598
Cycles Since Last Shop Visit (CSSV)	3235
Hours to Cycle Ratio Since Shop Visit	4:82

Table 3.4: Main Work Performed in the Last Shop Visit. Source: Batalha (2012)

Main Work Performed in the Last Shop Visit	
Component	**Work**
LPC[19]	Repair
Fan	Repair
HPC[20]	Overhaul
DBS[21]	Technical Performance Restoration
TNZ[22]	Technical Performance Restoration
HPT[23]	Overhaul
MGB[24]	Repair

Table 3.5: ECM Parameters ESN 724616 – 15SEP2001. Source: Batalha (2012)

ECM[25] Parameters	ESN NNNN	Other engine
Cruise Delta EGT[26], °C	42.6	18
Cruise N1 Vibration	1.7	0.4
Cruise N2 Vibration	0	0
Take Off EGT Margin, °C	10	37.4
Delta WF (Fuel Consumption) %	10	2
Oil pressure	220	190
Oil temperature	120	120

[19] Low Pressure Compressor

[20] High Pressure Compressor

[21] Diffuser and Burner Section

[22] Turbine nozzle

[23] High Pressure Turbine

[24] Main Gearbox

[25] Engine Condition Monitoring

[26] Exhaust Gas Turbine

3.2.2 Fleet management business case study

In order to understand better aero engine MRO process, in this section a specific industrial case will be analysed. Information here reported is a general view and evaluation of the MRO activities on military engines performed by a firm partner of DTA.
The firm considered has relationships with three different types of suppliers to perform its MRO process:

1. suppliers of spare parts (these relations are stable and continuous);
2. small accessories MRO firms (stable but occasional relationships);
3. suppliers that perform repair activities using other technologies not used by the firm itself (occasional relationships).

According to a study conducted by Corallo et al. in 2010, firm's MRO process can be divided into three sub-processes: engine receipt, engine overhaul and engine delivery.

In *Engine Receipt* sub-process, the MRO provider receives delivery note of engines from clients, inspects engines after transportation in order to check any issues, and finally stocks them in the warehouse. The engines are in the warehouse until the client requires the MRO operations through a PO (in some cases this can take days or weeks). For this reason warehousing costs are high and the process is lengthy.

In *Engine Overhaul* sub-process, MRO operations on engines are carried out, testing and certifying at the end the quality of results.

In the last sub-process, *Engine Delivery,* invoices are issued and the engine is delivered to the client.

In the firm, performance related to the whole MRO process is evaluated by the following set of metrics:

- *Mean TAT (Turn Around Time)*: the average time necessary for the overhaul of an engine or an engine component;
- *Mean cost of overhaul*: the average cost sustained for the overhaul of an engine or of an engine component;
- *Mean number of penalties*: average number of penalties paid by the firm due to failed contract fulfilment;
- *Number of engines in WIP*: total number of engines with a Work In Progress status at a specific time;
- *Punctuality of delivery*: number of engines delivered in time with respect to contractual specifications;
- *Stocks*: quantity of available stock;
- *Manpower utilization*: indicates efficiency in the utilization of human resources in the process.

Currently, the main challenge related to this process is to optimize times and involved resources, since mid-term forecasts on the flow of engines in arrival are not possible due to unavailability information from customer. For this reason, the process flow is discontinuous: there are periods of under-utilization of human and technical resources and periods in which the arrivals exceed the plant capacity and bottlenecks in the entire MRO process appear. Another consequence concerns procurement activities, as high stock level of spare parts and raw materials is necessary to meet the changing operational needs but determines high costs.

The main issues in the MRO process concern the lack of a simulation system able to optimize the scheduling operations with respect to specific priorities and available resources, the need to report the engine status to clients (both during MRO operations and at any time following receipt), and the use of ISIS[27] in only a limited number of programs (Corallo et al., 2010).

3.2.3 "As is" model of aero engine overhaul process

The actors taken into account in the present analysis are: *Airline/Air force* that requires overhaul activities on aero engines, *MRO Service Provider* who performs overhaul activities required by airline/air force, and *Suppliers* of MRO service provider.

It is useful to underline that airline/air force and MRO service provider subscribe a framework agreement in which general business target and constraints are defined[28]. In particular, they define how many engines belong to the fleet and the time span of the contract (some years), the time required for standard MRO operations and other quality performances of the service, the costs for specific operations, the penalties, and other minor issues.

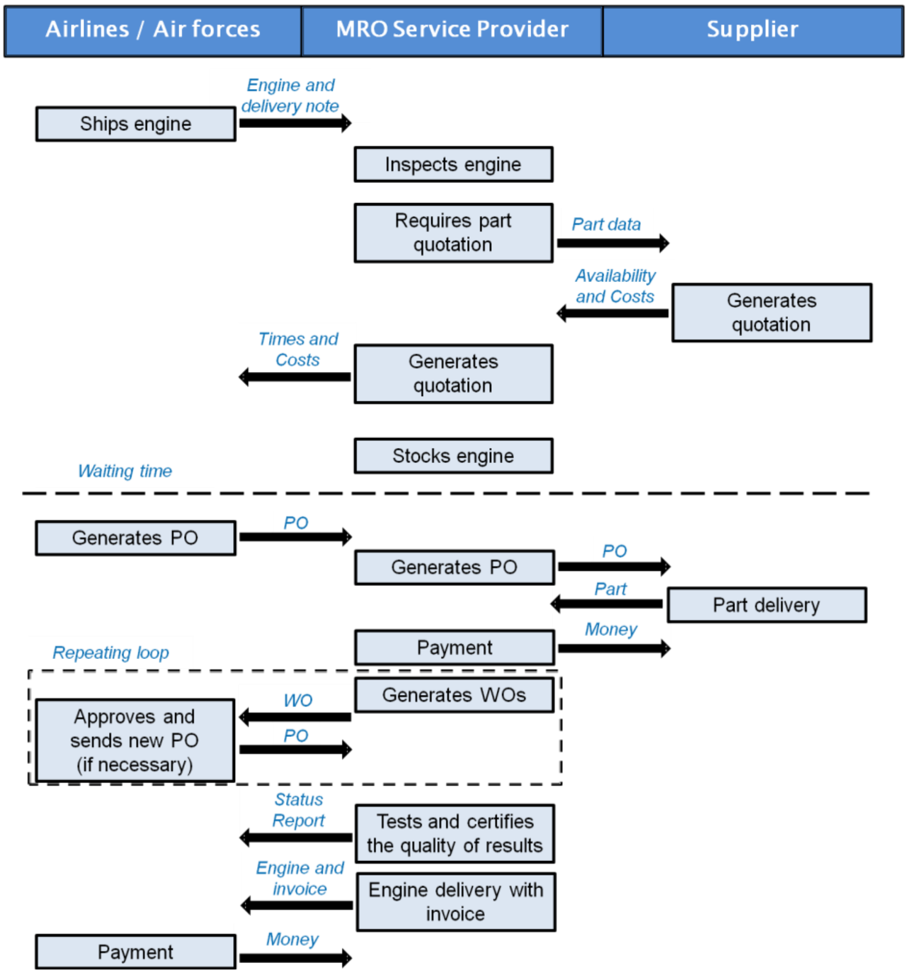


Figure 3.7: Aero engine MRO process: Activities and Data Flow

[27] In Service Information System is an advanced MRO Management system used by the firm as a fleet management service.

[28] In the analysed case the 'time and material contracts' type is assumed, as it is yet the standard for our partner. In general, this contract type is reducing its diffusion.

In the Figure 3.7, all the activities and data flow of aero engine overhaul process are described; it was considered as starting point the moment in which the engine needs to be overhauled.

The process analysed starts when the airline/air force ships its engine with appropriate delivery note to MRO service provider, who inspects the engine in order to check its conditions after transportation. After a careful inspection, MRO service provider requires the quotation to suppliers for parts or components to be substituted, giving to suppliers detailed parts/components data. Suppliers generate the quotation in which their availability and costs are reported; in this way MRO service provider is able to define a quotation for airline/air force, specifying costs and times to perform necessary MRO activities. Hence, the engine is stocked in MRO service provider warehouse until the client decides to send a purchase order (indicating types, quantities, and agreed prices for services required) to its.

When the MRO service provider receives a purchase order from airline/air force, it is able in turn to send purchase orders (specifying types, quantities, and agreed prices for parts demanded) to suppliers, which deliver what was required with times and costs previously agreed.

Only at this moment the MRO service provider starts the activities on the engine and sends work orders to client as the work goes on. The airline/air force can approve the overhaul activities performed or send new purchase orders to MRO service provider in order to change instructions.

At the end of overhaul activities, the MRO service provider first tests and certifies the quality of results, writes a status report for the client, and then delivers “the new” engine, with appropriate invoice, to the airline/air force.

The process ends with the airline/air force payment for MRO services received.

3.2.4 Cloud Planning System for collaborative overhaul management

Currently, the MRO service provider has only limited capabilities to forecast demand and therefore plan capacity. Demand is driven by both, time of engine receipt and time needed to overhaul the engine. In order to meet the contractually defined mean turnaround time (TAT), a capacity buffer is needed to deal with volatile demand.

In this section, an innovative collaborative scenario applicable to the aero engine overhaul process, the Cloud Planning System (CPS), is proposed. In particular the services provided by the system to the supply chain actors, the benefits they will bring, and which data are required to compute them are proposed. Such a system answers the need to quickly plan and execute the aero MRO activities, according to the flight hour contracts (in which the customer pays a predetermined rate per flight hours) that are rapidly spreading in the industry.

The CPS is a programmable platform which allows all the actors (airline/air force, MRO service provider and supplier) involved in the process to improve performance through efficient services by securely sharing their private data. This system is based on Secure Multiparty Computation (SMC), a method that, as it will be detailed in the fourth chapter, will enable a number of networked parties to carry out collaborative computing tasks on private information (Bogdanov et al., 2012). Each party provides inputs and learns outputs such that no party can learn the inputs or outputs of another party (Bogdanov et al., 2013).

According to the arguments developed in the subparagraph 3.1.2.3, the Cloud Planning System is as a combination of the information hub model with the privacy-preserving method; in this way actors involved can securely share their private data, obtaining all the benefits of sharing in return.

Hence, if all actors involved in overhaul activities shared some of their private information in CPS, the overhaul activities planning could be optimized and the benefits could be prominent for all actors. In the following, only the overhaul process will be considered, without paying attention to situations in which the aero engine suffers damages.

3.2.4.1 Process optimization and services provided

The CPS, as said before, is a virtual machine for privacy-preserving data processing that gives to the participating actors a number of secure and efficient services. The two main business-optimizing services are collaborative overhaul demand forecasting (1) and collaborative overhaul planning and scheduling (2).

(1) Collaborative overhaul demand forecasting:

The MRO service provider obtains demand forecasts from all customers based on the on-condition engine status observation. The aggregated demand forecast (also incorporating MRO's own forecast) allows adjusting capacity while overhaul service levels as defined in the contracts. Potential overcapacity is shut down / reduced (technical equipment, contract workers) or shifted to different processes (technical equipment, employees – baseline flexibility required). Although this service has no positive effect on lead times, overall costs can be reduced due to more accurate capacity planning.

(2) Collaborative overhaul planning and scheduling:

Once a more accurate demand forecast is available for the MRO service provider, additional improvements are possible. Since forecast and already booked overhaul plan and capacities are known, the MRO service provider can determine an ideal receipt point for each engine. Whereas the forecast not only includes the most probable receipt point but also the engine status, typical net turnaround time for each specific engine can be computed. Using this information and combining it with production plan and capacity, a lead time minimizing receipt point can be computed. Prerequisite for optimization is that the airline / air force acts upon the MRO service provider's recommendation or even transfers the overhaul scheduling rights to the service provider, on the other hand receiving cost benefits and shorter and more stable turnaround times.

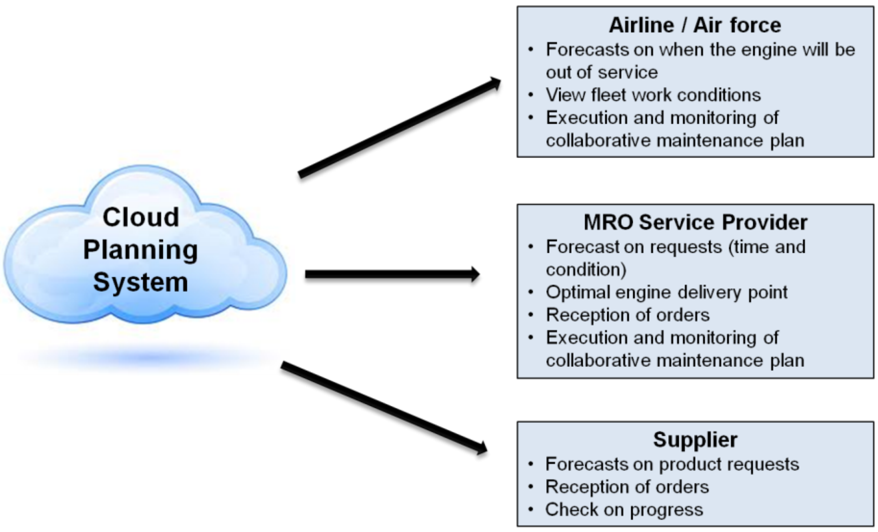


Figure 3.8: Cloud Planning System: Services Provided

Also, by taking more accurate demand information into consideration, lead time and cost improving capacity optimization could be considered, meaning e.g. to determine the number of flexible overhaul lines versus dedicated lines.

Additional services that could be provided by CPS are displayed in Figure 3.8[29].

The airline/air force can receive:

- Forecasts regarding overhaul requirements and engine conditions on individual engine level,
- A complete overview on its engines fleet, that includes work conditions, required overhaul activities (if applicable) and opportunities for scheduling next MRO checks (if applicable),
- Execution of the collaboratively planned overhaul services,
- Checks on the progresses of the overhaul activities carried out by the service provider and on their relation with the approved plans.

The MRO service provider can obtain:

- Forecasts regarding overhaul requirements and engine conditions on individual engine level for all customers (airlines/air force),
- Optimal delivery points for upcoming engines to be overhauled based on already booked production plan and capacity,
- Orders plans from airline/air force (in terms of purchase orders),
- Execution of the collaboratively planned overhaul services and checks on the progresses of activities carried out by suppliers and on their relation with the approved plans.

At the end, the supplier can have:

- Forecasts on product requests,
- Orders plans from MRO service provider (in terms of purchase orders),
- Checks on the progresses of activities carried out in the supply chain and on their relation with the approved plans.

The UML activity diagram (Figure 3.9) shows the different activities of the collaborative supply chain management. The activities are separated into 3 phases:

1. Demand forecasting phase,
2. Supply planning computation,
3. Supply Plan Execution / Monitoring.

The diagram begins in the demand forecasting phase. The three parties of the aeroengine fleet supply management (MRO, airline/air force and supplier) sends data to the cloud planning system (CPS). MRO provides working plan and inventory status, the airline provides engine work and status data and the supplier provides production plan and inventory data. With the received data from the participants the CPS can calculate unplanned maintenances and/or planned overhauls. These are parts of the supply planning computation. Once an event occurs in the CPS, the system notifies all participants.

[29] In the time of preparing this report, the system is not available yet nor its feasibility was evaluated, in the section expected functions are presented.

After that the airline sends its engine to the MRO. Likewise the supplier delivers the replacement parts to the MRO. After the MRO receives everything, they begin to overhaul the engine. These steps are part of the supply plan execution / monitoring phase. Finally the engine is send back to the airline which is the last step of the process.

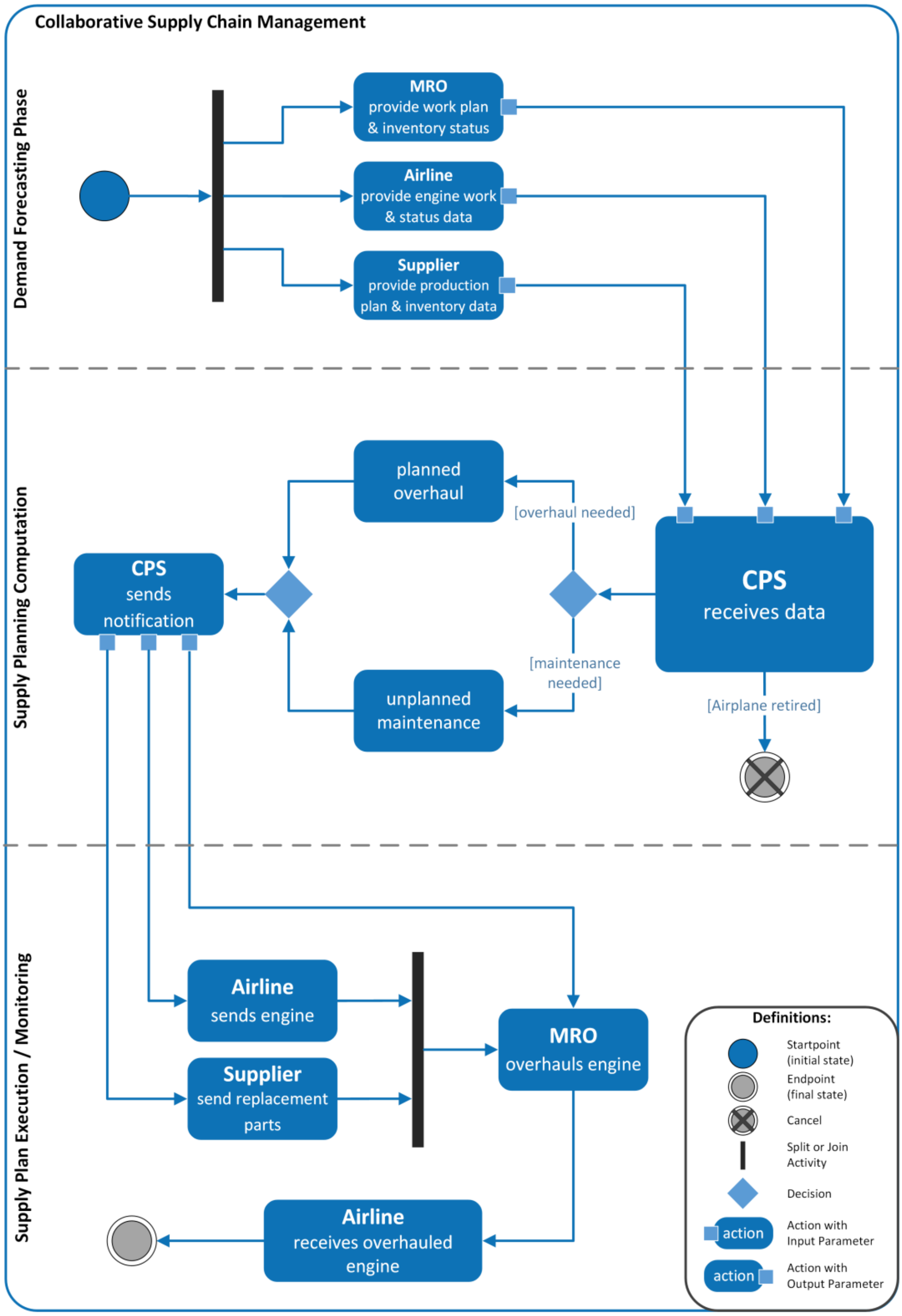


Figure 3.9: UML description of the collaborative MRO planning process.

3.2.4.2 Benefits for aerospace industry

Today, aerospace MRO industry needs are related to the lack of IT systems able to optimize the scheduling operations, to report in real time performed activities status to clients, and to manage fleet management services in a systematic and continuous way.

The CPS, as designed in the proposed scenario, enables new types of collaborative relationships and processes among business partners: 1) the optimized capacity planning by using the private customer forecasts and 2) the collaborative MRO service planning.

The actors involved in the partnership share their private data with the secure planning system, which gives useful services in return, without disclosing data to other partners. With such system performing and managing collaborative activities involving different supply chain partners, process inefficiencies (such as excess costs or inadequate service performances) are reduced and a real time activities planning is possible.

These benefits can be obtained only thanks to the security properties of the system: the actors involved avoid sharing with business partners their private data.

In the end, the CPS also has a significant positive impact on a number of metrics among those usually used to monitor a typical MRO process (they were all reported in paragraph 3.2.2):

- *Mean TAT* can be reduced since the management of MRO activities will be optimized (more efficient scheduling) and there will be less problems with the resources availability if they were required;
- As a direct consequence*, Mean cost of overhaul* can be decreased because of the availability of the right resources in the right times and the reduction of stocks level (wastes will tend to zero);
- *Number of engines in WIP* will be maximized in function of the work to perform and the available resources, so that the MRO process flow will be continuous (without having periods of under-utilization of resources followed by periods in which the arrivals exceed the plant capacity);
- *Stocks* will always be available when required and their level in internal warehouse will be reduced, since the system is able to forecast, in a reliable way, the number of engines to be overhauled.

The fact that these metrics may have better values thanks to the CPS adoption shows the high performance role of the scenario proposed.

3.2.4.3 Input data

Each actors provide in the *CPS* specific private data in order to obtain high performance services (Figure 3.10).

In particular, Airline or Air force actor provides *CPS* with the engine data. In other words, they shares information about:

- *Engine Status*, that includes engine serial number, aircraft type, registration, position number, date of last shop visit, hours since last shop visit (or since new), cycles since last shop visit (or since new), hours to cycle ratio since shop visit;
- *Main Work Performed in the Last Shop Visit,* in which the work performed on the different engine modules (low pressure compressor, fan, high pressure compressor, diffuser and burner section, turbine nozzle, high pressure turbine, main gearbox) is specified;

- *Engine Condition Monitoring Parameters,* such as cruise delta exhaust gas turbine, cruise N1 vibration, cruise N2 vibration, take off exhaust gas turbine margin (°C), fuel consumption, oil pressure, oil temperature, just to mention some of them.

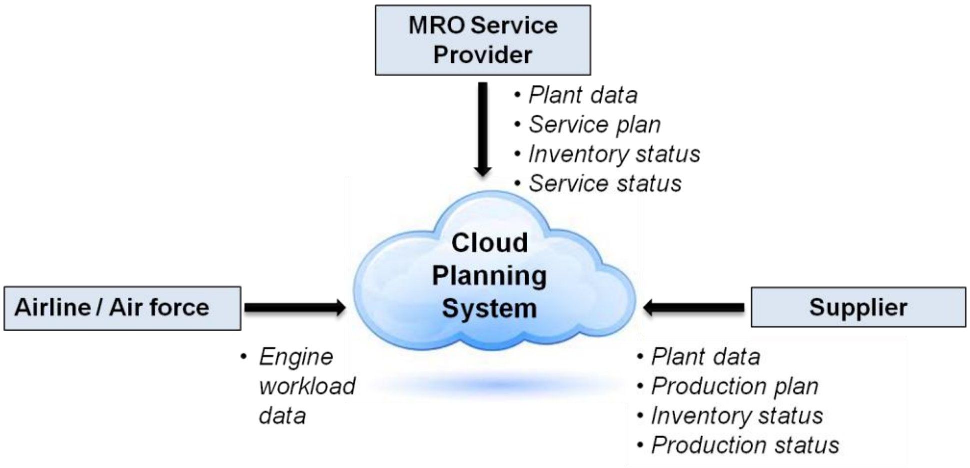


Figure 3.10: Cloud Planning System: Input Data

MRO Service Provider puts in CPS the following data:

- *Plant Data,* in this data section the production capacity in terms of number of engines maintained per day, and times and costs for each service provided are specified;
- *Service Plan,* where the number of engines to be maintained in the next programming periods is detailed;
- *Inventory Status,* that includes all parts and components available in the inventory;
- *Service Status,* where the work in progress within the MRO shop is reported.

Supplier contributes to Cloud Planning System with:

- *Plant Data,* that contains information about the production capacity in terms of number of work performed/part made per hour, and times and costs for each processing;
- *Production Plan,* in which the number of processing/part to be carried out in the next programming period are reported ;
- *Inventory Status,* where all components present in the internal warehouse are reported;
- *Production Status,* that gives information about the work in progress in the plant.

In the Table 3.6 below are summarized all actors input data.

Table 3.6: Input data summary.

	Airline/ Air force	MRO Service Provider	Supplier
INPUT DATA	**Engine Status** • engine serial number, • aircraft type, • registration,	**Plant Data** • production capacity (number of engines maintained per day), • times and costs for	**Plant Data** • production capacity (number of work performed/part made per hour),

	Airline/ Air force	MRO Service Provider	Supplier
	• position number, • hours (time) since new, • cycles since new, • date of last shop visit, • hours since last shop visit, • cycles since last shop visit, • hours to cycle ratio since shop visit	each service provided	• times and costs for each processing
	Main Work Performed in the Last Shop Visit Work(s) performed on the different engine modules	**Service Plan** Number of engines to be maintained in the next programming period	**Production Plan** Number of processing/part to be carried out in the next programming period
	Engine Condition Monitoring Parameters • cruise delta exhaust gas turbine, • cruise N1 vibration, • cruise N2 vibration, • take off exhaust gas turbine margin (°C), • fuel consumption, • oil pressure, • oil temperature	**Inventory Status** List of parts and components available in the internal warehouse	**Inventory Status** All components present in the internal warehouse
		Service Status List of work in progress within the MRO shop	**Production Status** Work in progress in the plant

3.3 Application to Consumer Goods Industry

3.3.1 Planning in Arcelik

In general, for supply chain management approaches, the main differentiator is the production strategy, which is indirectly connected with turnover and profit making targets. If a product is created according to a specific customer demand, it is a “make to order” strategy. Oppositely if the production is handled with an anonymous manner, it is a “make to stock” strategy, which is also adopted by Arcelik on its supply chain management approach. In a typical “make to stock” environment, planning is triggered only by independent requirements and therefore demand planning is playing a key role. “Make to stock” strategy is applied since the same products are usually sold to many customers and the lead time of the sales orders has some uncertainty.

Another characteristic of the supply chain in Arcelik is that sourcing alternatives exist. Multiple sourcing options are available for suppliers and in many cases alternatives exist for production and distribution as well. Common variants in the distribution are direct shipments from the plant to the customer (instead from the local distribution center) depending on the order size. The most common supply chain processes are demand planning, order fulfilment (sales, transportation planning), distribution (distribution planning, replenishment), inventory planning (safety stock planning) and production (production planning, detailed scheduling, production execution).

The demand netting process is currently affected by local supply chains of subsidiaries. The result is the purchasing quantities from the plants that are uploaded to SOP tables. The upload is done by international order management at the head quarter located in Turkey.

Local stock structure and stock levels are monitored and decisions are finalized by central supply chain, inventory planning department. The determination of the appropriate safety stock levels in supply chain depends on the deviation of the forecasted demand from the real demand and the deviation of the supply, the supply chain network, the product structure and the targeted service level.

The time lag between placing the order and receiving the supply, the insecurity about the future orders on the demand side and the insecurity regarding the stock outs on the supply side usually cause overreactions for the own orders. The behaviour is known as “bullwhip effect”. The tendency for lower levels in the supply chain to batch orders in this way is one of the root causes of the bullwhip effect.

3.3.2 Consumer goods planning and distribution case study:

The purpose this section is to provide a high-level overview of the case study, focusing on the understanding the as-is processes.
The section is built as follows:

- First, we explain the normal as-is processes, including the main steps of the process as well as the important stakeholders involved, the type of activity and the content of the information exchanged together with information about the communication channel(s) used,
- Secondly, main challenges are listed. The identified challenges highlight the demand for new technologies and may give an indication of where their application can have the greatest impact,
- In the final part of the section, we explain how the future might look like with the help cloud based information sharing and secure computation of data.

The story is built around the planning process of Arcelik and focuses on the collaboration between different actors in the chain. The figure given below schematizes all the main stakeholder involved case study and their interactions.

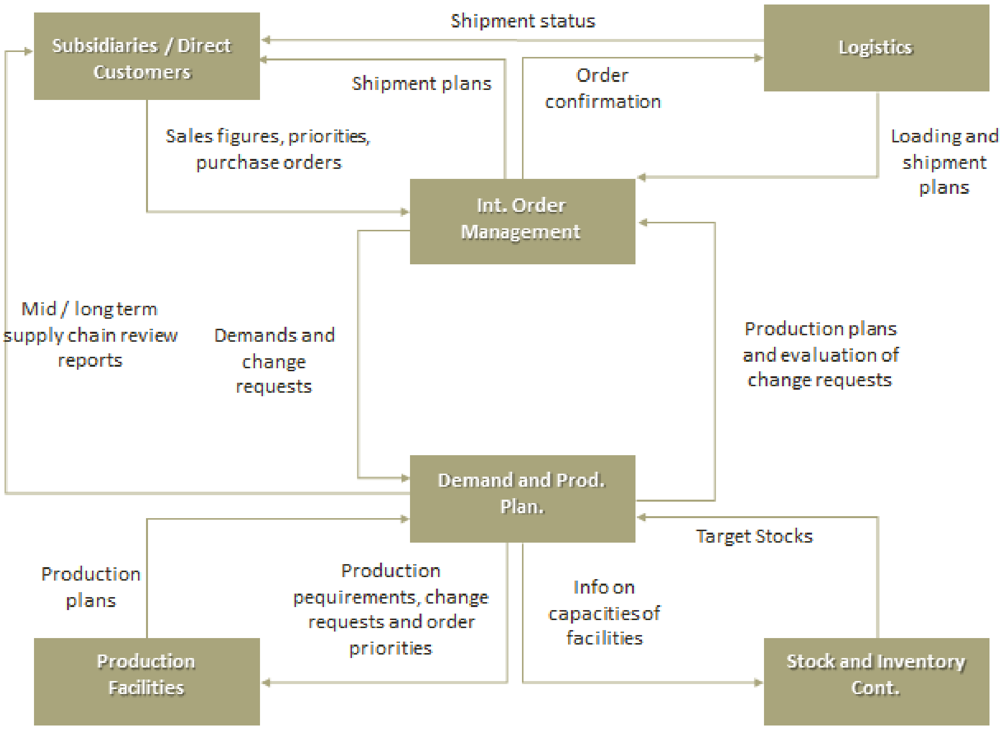


Figure 3.11: The main stakeholder involved in the Arcelik case study and their interactions.

In Arcelik, production process starts with forecasts and orders of the direct customers and subsidiaries. At that point, it is important for them to achieve past data in safe and quick way. Moreover, Arcelik does not want to share its complete sales figures with all the clients. For instance, Arcelik does not need to share sales figures of BEKO PLC (Subsidiary in United Kingdom) with BEKO LLC (Subsidiary in Russia) or any direct customer.

Subsidiaries and direct customers then send their forecasts and orders to International Order Management department to let them enter these figures into the SAP system. These data are consolidated and arranged by International Order Management prior to SAP entry. This process is performed via using Production-Sales-Stock (PSS) files of each country. Only country responsible can see PSS file of the relevant country; and these files must not be displayed by others. Then International order management department responsible enter data to SAP and let Stock management, Production and Demand planning departments to work further on this data.

Firstly, Stock management and inventory control department work on data to fulfil empty capacities of the production facilities. At that point, confidential data –like as production cost- and sales figures are used to determine the production plans and stock targets for the coming months.

Secondly, Demand and production planning department starts to work based on all the forecast and order figures with stock targets. This department first investigates the data to create the following months work plan. This work plan includes actions on the number of shifts for each line of the factories and daily production tempo of each line etc. These plans must be displayed only by Demand and production planning department. However, in some periods, Demand and production planning department shares a limited part of this overview as a report with subsidiaries to let them plan for the coming orders.

Then the Production planning departments starts to make their production plans of the relevant months. In this level, factories should see only relevant data about the plans and strategies in master degree are kept in Demand and production planning department. Factories shares their production plans with the supply chain head office.

According to production plans and the status of change requests, International order management department plans the shipments of orders and share these plans with Logistics department. These plans are also shared with the clients, but each client can learn about its own plans. Head office of supply chain never shares production plans with anyone. In the end shipment is organized and monitored by Logistics department in coordination with the customers.

3.3.2.1 Main Challenges (AS-IS)

Below the main challenges of the as-is business processes are summarized based on the perspective of Arcelik (central supply chain planning):

- Data sharing relies highly on manual efforts, only partially supported by ICT solutions.
- Highly sensible data is shared via emails etc. which might impose a risk to information security.
- Current system cannot provide required confidentiality since there is only limited control over the distribution of information to assure that only authorized people can reach information of which they have rights to view. In other words, visibility of relevant data by correct users is demanded.
- Information is distributed to different actors, hence might deviate from actor to actor due to different processing activities. There is limited visibility over the overall supply chain operations due to one-to-one info sharing and limited collaboration.
- Current system cannot support more dynamic and optimistic environment for algorithms used in calculations and planning processes since it is subject to delays, human errors and factors such as bullwhip effect etc.

3.3.2.2 Proposed System: Cloud Planning for Collaborative Planning and Monitoring (TO-BE)

A cloud based collaborative system for planning can exploit the benefits of future internet and new technologies on secure computation and cloud computing to overcome the challenges summarized in the previous section. The data that needs to be shared between departments (different actors in the chain) to ensure efficient collaboration and better alignment can transferred through the cloud server with encryption. It can introduce radical improvements on information security and the process of information handling.

In general, lean techniques of manufacturing can be applied due to the efficient flow of data inside the system. The system aims to avoid wastes –muda- (such as non-value added activities such as iterations due to one-to-communication, uncertainty due to limited visibility etc.) and the proportion of time and effort spent for value added activities can be enhanced. The system is open and flexible for improvements every time –kaizen-. A lean information sharing can be attained via cloud computing. The envisioned interactions between different actors are as depicted below.

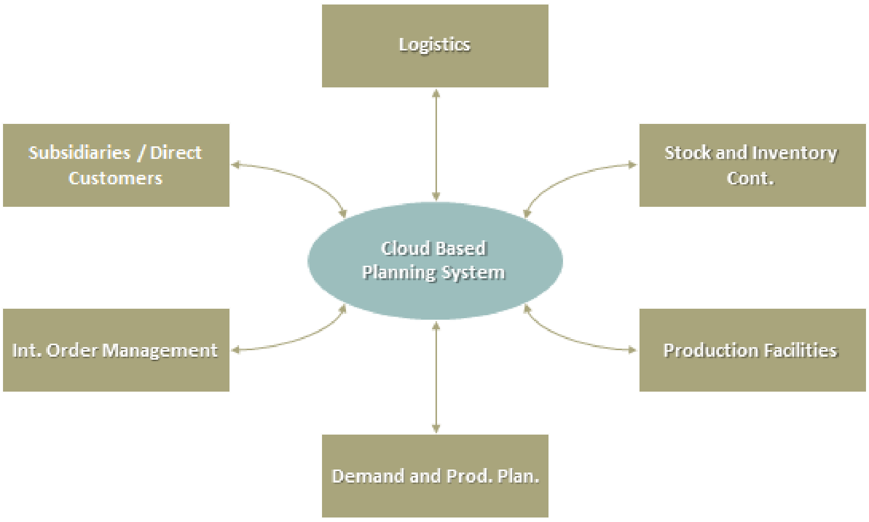


Figure 3.12: Expected data flow in a secure cloud based system.

In the proposed system:

- Subsidiaries and direct customers can directly see relevant parts of the production plans (if they have authorization).
- Logistics department can display production plans and can participate in the evaluation of change requests on production plans by pointing out the constraints and bottlenecks of the shipment process, leading to improved overall supply chain costs by linking the production plans to optimal shipment plans.
- Confirmation of the orders can be performed in the system and immediately shared with relevant departments from one source.
- Each country responsible can view its own stock data instead of whole stock data.
- Changes on the orders and production plans are directly reflected into the system. Therefore, it will be possible to optimize plans more efficiently and forecast future demands with increased accuracy.

The proposed system makes it possible to avoid individual data processing and assures up-to-date data transfer from one source. All individual manual processes are joined inside the new cloud system which will in turn create the right balance between production and shipment planning leading to decreased level of uncertainty and stock levels of Arcelik.

Chapter 4 Secure cloud-based collaboration

4.1 Cloud Computing

As seen in the previous sections it is well-acknowledged that collaborative planning between different members of a supply chain can increase the overall performance.

The amount of data exchanged between members directly impacts the effectiveness of the collaborative planning. In fact, a complete knowledge of the supply chain is fundamental for the definition of a reliable and effective master plan, capable of guaranteeing the success of the system as a whole, instead of basing the strategy of the supply chain on achieving a local optimum for each actor.

For this information sharing all the actors must release their data to one master planner. This information sharing can be achieved using different approaches.

1. All information flows are transmitted without any encryption, or other privacy preserving methods, and so everything is visible to all the actors. This approach is often called the whiteboard approach and is very efficient in terms of computing the master plan since communication and computation overhead is minimized. On the other hand, every actor needs to share all information with all other participants. That includes data which is considered to be confidential. Hence, in order for this approach to be taken, every participant has to trust every other participant in this scheme. This may work for a small number of actors in this scheme, but the larger the group becomes, the higher is the probability of one member of the group not wanting to share data with another member.
2. To weaken the trust requirement of the first approach, a second approach is to involve only a single trusted party. That party can also be a member of the supply chain. In this setting, all members disclose their data to that trusted party, instead of to all other parties so that their information will stay confidential to other parties of the supply chain.

The upcoming trend of cloud computing in information technology offers new ways for collaborative planning, forecasting and management of supply chains, especially w.r.t this second approach.

Cloud computing fits perfectly in the scenario of master planning in supply chain collaboration with its essential characteristics (defined by NIST SP800-145). These characteristics are:

1) **On-demand self-service**. Computing capabilities (e.g. network storage, server time) can be provisioned as needed without human interaction with the service provider. With a few clicks of a mouse the customer can allocate new resources (typically on a web interface). Thus, setting up new projects is less time consuming and can be rolled out way faster.

2) **Broad network access.** The services are accessed with standard mechanisms over the network and can be used by different client platforms such as mobile phones or laptops. Since we assume different actors of the supply chain as partners and facilities at different geographic locations a fast network is crucial. Via a broad network it is possible for partners to access their information from everywhere at every time in an easy way.

3) **Resource pooling.** The service provider's resources are pooled by multiple customers dynamically. Thus, the waste of cloud provider's resources is kept to a

minimum level not only with regard to economical but also ecological aspects. In addition, the customers do not know where the physical resources are located exactly but they may be able to specify the location (e.g. country or region) for legal reasons.

4) **Rapid elasticity**. The customers can request and release the computing capabilities dynamically. Even in situations of fast changing circumstances (e.g. Christmas trade for toy factories) the computation capabilities can be used in an optimal economical way. Additional hardware that is used only for a short period of the year and idles the rest of the time is not needed anymore.

5) **Measured services**. The use of resources is measured and can be monitored and changed by the customers. Every actor of the SC can keep track of the costs and energy used for the collaborative planning. This guarantees transparency for the customers and the cloud provider.

To guarantee the separation of different cloud customers' data, techniques for virtualization are essential. Other benefits of this virtualization are flexibility for both the cloud provider and the customer. On the one hand, the cloud provider is able to change underlying hardware settings without changing the customer's settings, on the other hand the customer is able to move his data to another cloud provider by copying her virtualized image (if this image is created, saved and load in a standardized way).

In addition, data may be stored in multiple locations to increase the reliability by redundancy. These different locations may be interconnected via private glass fibre optic cables with no direct connection to the internet to increase security. Due to this decentralized approach, a customer can access her data even if one data centre of the cloud provider is out of order (e.g. due to an earthquake or power failure). Moreover, load balancing between different geographical locations can result in improvements related to computational performance (e.g. by sharing complex computations between data centres) and network performance (e.g. by choosing geographical nearest data centre).

No need of dedicated servers with expensive computer network infrastructure for every SC party is another positive effect of outsourcing the data in the cloud. Thus not only expensive hardware but also maintenance and periodic hardware updates are not necessary. Monetary savings for powering and cooling systems will become even larger in the future due to continuously rising energy costs.

Furthermore, the cloud provider is specialized in the topic of outsourced data, and hence the provider's administrators may have a better know-how and may be specialized in topics like security (e.g. intruder detection, filtering, update management), backup practices and network configuration. This results into staff savings for the customer and better configured computation environment.

Transferring the monetary and organizing effort to the cloud provider is one of the main issues for customers to choose cloud-based approaches for processing computations. Especially small and mid-sized businesses may take advantages of cloud-based services since they can save know-how and expensive infrastructure. This kind of businesses is often involved in SC-based planning and forecasting. However, as discussed in this section, all participants gain additional benefits especially for the scenario of centralized master planning.

4.1.1 *Obstacles preventing cloud-based collaboration*

However, companies are not willing to share their confidential sensitive data (e.g. capacity data or costs or used goods) with other participants or a central unit like the cloud service provider. They fear the risk that other companies involved in the supply chain exploit this information in order to maximize their profit.

So the benefits of cloud computing for centralized master planning cannot be achieved in practice because of three major issues:

1) Alignment of individual decisions to SC-wide objectives,
2) Delegation of decisions to a central planning unit,
3) Sharing sensitive data.

Alignment of Individual Decisions to SC-wide Objectives

A centralized approach requires all partners to arrange their decisions to the common objective of minimizing the overall SC-wide costs. The fact that each party tries to achieve its own goals, i.e., individual cost minimization, a centralized master planning model can be interpreted as a solution of a multi-objective decision problem based on trade-offs between individual objectives. One party will only accept this compromise solution if its individual costs are minimized as well. But this can rarely be observed in practice; at least one party will often be at a disadvantage if the centralized approach is realized.

Hence, in a centralized master planning scheme some individual parties may have appeals to report false data or forged partial results in order to gain advantages, e.g. minimize their local costs or increasing costs of their competitors.

Delegation of decisions to a central planning unit

A centralized approach can only be implemented if one planning domain exists that has the power to enforce a centralized approach on all other planning domains involved in the SC. This central planner needs the union information that only all individual parties have. Every party has to trust this central planner to do the correct calculations based on the individual inputs. In reality this trust is not given in many cases. Especially for outsourced data the risk of insider attacks are growing dramatically. For instance a competitive party may try to get access to the cloud provider's data centre (e.g. by social-engineering or corrupt insiders) to fake these calculations.

Sharing Sensitive Data

Another major obstacle that has to be taken into account when implementing a centralized master planning approach in reality is the sharing of sensitive data. Partners involved in the SC may hesitate to share their private data and to report truthfully due to the following reasons:

- The central planning unit or other parties may misuse sensitive data (e.g. cost and capacity information) in order to obtain additional benefits. Again, the privacy of this data is risked by inside attackers and outside attackers.
- By providing false cost and capacity information parties may increase their profits under certain circumstances.
- Providing the relevant cost information may lead to lower volume allocation in the future and to disadvantages when negotiating purchasing and supply quantities.

All partners have to keep all these issues in mind when deciding upon sharing relevant sensitive information with other parties.

While a good legal framework may help to ensure that confidential data is not abused, a technical framework could help the adoption of cloud based services to leverage their benefits. A technical framework needs to ensure that, amongst other things, private data cannot be read by untrusted parties. If such a framework existed, companies could trust cloud based services more easily and supply their confidential data to optimize the supply chain.

4.2 Secure Multiparty Computation (SMC)

Fortunately, such a framework can be built using a technique called Secure Multiparty Computation (SMC). SMC uses cryptographic primitives and protocols and can be used to ensure no private data being read by untrusted parties. This framework is a promising way to overcome the problems for centralized master-planning. In an ideal scenario every participant transfers encrypted data into the cloud where computation is executed in a secure manner (see Figure 4.1).

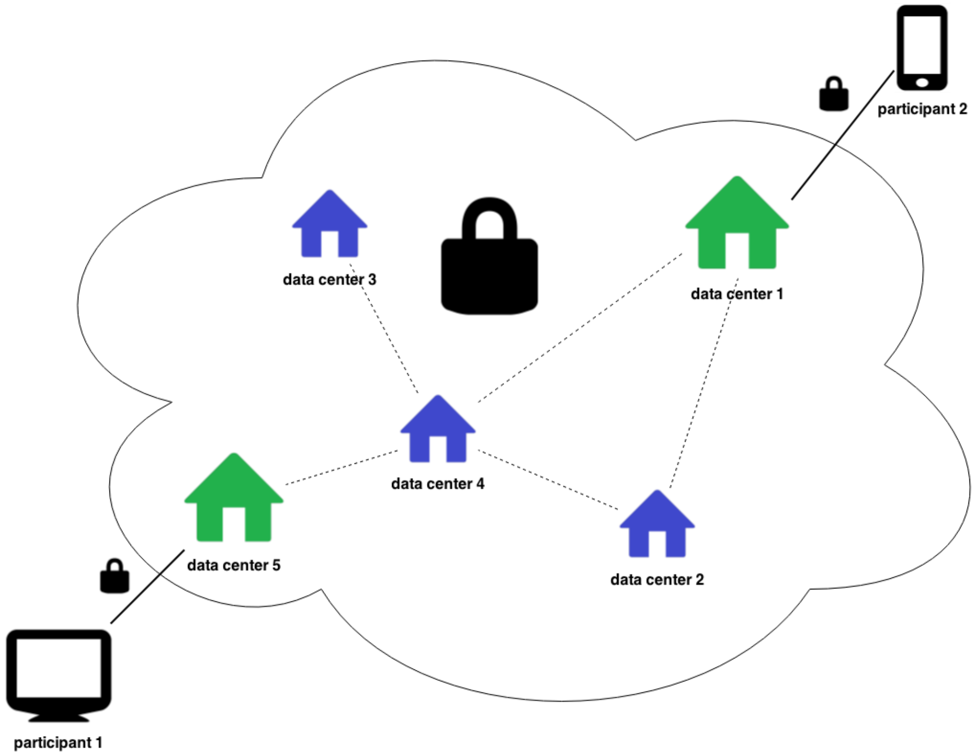


Figure 4.1: Ideal scenario for secure cloud computation, dotted lines illustrate internal network

The following section will give more details on SMC and its applications.

4.2.1 Definition of SMC

Using SMC, one can implement the calculation of the objective function without showing or revealing data considered to be sensitive or confidential. Since no data sharing risk is left, this approach offers the ultimate level of protection. Combined with the benefits of cloud computing these techniques are a powerful tool for central planning in a secure manner.

To exemplify the SMC scenario, we consider a group of n parties, P1, …,Pn that want to carry out a joint computation. One of the examples of a joint computation is an auction with secret bids, the average of secret inputs, or cloud-based supply chain management services. SMC can be realized using cryptographic tools and protocols designed specifically for that purpose. These security requirements can be distinguished between privacy and correctness.

- **Privacy:** It should be ensured that the computation can be carried out without leakage of information about the parties' private input data. An expectation is made to information that one can infer of her own input and the given output.
- **Correctness:** We expect that every honest party gets the correct output of this joint computation. That means the output is equal to the value of this computation for all given inputs. In addition the outputs should be consistent and the computation terminates where all honest parties getting their output.

If the output and one or more inputs are known, it is often possible to infer some information about other inputs. Depending on application and setting such information leak may be acceptable or not. For example, if two parties P1, P2 compute the average of their private input values X1, X2 and both get the average (X1 + X2) / 2 as output, it is easy to determine the input of the other party, so input privacy is not possible. However, the privacy property as stated above, is not violated in this case.

On the other hand there are well known protocols that realize auctions with secret bids, i.e. without revealing information of the other bids, except the order relation of the winning bid and the other bids.

In literature there are a lot of cryptographic protocols that make collaboration in a secure manner possible. But it is very important to define the security requirements and the power of adversaries such protocols in a well-defined security model. The various kinds of adversarial behaviour faced by security protocols are usually modelled by a single adversary able to control different aspects of protocol execution. To model the collusion of different participants, the adversary is assumed to be able to corrupt a subset of participating parties and thus gains access to their secret data and even control over their behaviour. Such a corruption could occur either by bribing or blackmailing the participant, or by manipulating their computing environment, i.e. to see their inputs to the computation.

Although correctly following a protocol, a player may for instance try to gain more information from exchanged secret data than she is supposed to. A participating party that behaves in this way is called a passive adversary. On the other hand, an active attacker (or malicious adversary) may abort the protocol preliminarily or try to deviate from it (e.g. in the case of SCM to increase her advantage). In order to overcome such active adversarial behaviour, Goldreich, Micali and Wigderson (Goldreich, 1987) published an algorithm which (with additional computational costs) does compile a given protocol which is only secure in the semi-honest model (private protocol) into a protocol that also is secure in the malicious model (robust protocol). This is accomplished by forcing players to prove in zero-knowledge that they followed the given protocol. Thus, any deviation is detected and in that case the player is revealed being cheating.

Regardless what exactly the adversarial behaviour is (i.e. active or passive), the point in time when a player starts behaving adversarial may vary. Players can behave maliciously immediately from the beginning until the end of the protocol run – that is what is called static (or non-adaptive). Players can, however, also decide to become adversarial dynamically upon a certain state or event during the protocol run. That is what is called a dynamic (or adaptive) adversary.

Whatever the chosen model is, security is considered usually in an information-theoretic sense on the one hand and in a cryptographic sense on the other hand. Information-theoretic (or perfect, unconditional) security means that even an adversary with unlimited computing power is not able to violate secrecy. Cryptographic security instead relies on an assumed restriction on the adversary's computing power and on certain (often unproven) assumptions about the hardness of some computational problem, e.g. factoring large integers.

In theory the protocol announced by Yao (Yao, 1986) is a general method for evaluating two-party functions (i.e. two parties that do joint computation), with passive security, in constant rounds. This function must be specified as Boolean circuits. It has become one of the main methods for secure computation in the two-party setting and has also been adapted for the multiparty setting. However, for (complex) computations in the multiparty setting this approach is far too inefficient. On the other hand, there are efficient protocols that are suitable for special operations. Some requirements and scenarios for these specialized tools will be discussed in the next session.

4.2.2 Special tools for secure cloud-based collaboration

4.2.2.1 Encrypted Databases

One crucial aspect for parties to apply centralized supply chain collaboration successfully is the possibility to control their inventory (e.g. capacity information or fleet status) in a secure way. This enables every member of a party (with given permission) to monitor and update all important data from everywhere at every time.

For instance, suppose a truck has an engine breakdown and the trucker can immediately report this to the cloud by his mobile phone. The cloud has the information what goods are loaded and what the destination of the truck has been. In addition, the global fleet status is known by the cloud so it can send the nearest truck with the same payload or enough free capacity to reload the goods from the broken truck. Even a business partner’s truck can be sent if its current position is known by the centralized master planner. With these abilities it is possible to minimize the downtime and react in an ideal and automated way to unexpected event. Businesses would profit in that scenario, as it would be possible for any participant to react dynamically such that the truck maintenance company could be informed immediately and in turn order spare parts whereas the company depending on the goods in the truck could prepare for a short delay in delivery instead of being surprised and having stalled production lines.

However, as already mentioned above, the privacy of this information (i.e. the fleet status) is the major obstacle to implement this scenario in practice. Competing business partners that be able to track all trucks and create a detailed profile that may reveal additional information (e.g. focus of current or future business, business partners, etc.). Motivated by this example a technique for storing data - and processing this data - in secure manner appears useful.

Naive approach

The obvious approach for storing data in a secure way could be to encrypt all information with a secure algorithm such as AES and transfer this encrypted database to the cloud. This method leaks no information (under the assumption of using a secure encryption algorithm). However, processing the database in the cloud is no longer possible as the database is not aware of the encryption and cannot perform operations such as comparing two ciphertexts or sum up values in the database. Thus, the encrypted data has to be downloaded to the client (that knows the decryption key), decrypted, and only then one is able to execute queries on the decrypted database.

Obviously, this solution has a severe communication overhead as all encrypted data must be transferred, edited, reencrypted and transferred back in the cloud. Interestingly, this is the way most traditional Database Management Systems appear to work when they claim to encrypt data and provide secure cloud storage. This overhead would be mitigated if the database is aware of the encryption and can perform operations directly on the encrypted data. The data then can remain on the server and does not need to be transferred to the client and back to the server.

Encrypted Database with possibility to perform operations on encrypted data

To implement that approach, one could encrypt data in a way that enables the cloud to execute some kind of queries and computation on this encrypted data. These operations may be:

- equality checks
- comparison of encrypted data (i.e. computing an order relation)
- partially homomorphic encryption (i.e. adding encrypted numbers)

We use an example to motivate some useful operations on encrypted data. Suppose a database which stores the actual fleet status (see Table 4.1 below) and should be stored in the cloud in a privacy preserving way. That is, no other party shall be able to read the clear text values of the data. Only encrypted data shall be visible.

Truck ID	Truck Position	Truck Load Capacity	…
4	Rome	40	…
17	Rome	17	…
23	Munich	40	…
42	Rome	35	…
…	…	…	…

Table 4.1: Example for database

Given this table one may like to know things like:

- **What are the IDs of all tracks in Rome?** The row holding the encrypted value of the truck position must be *checked for equality* of the encryption of "Rome" and the truck IDs of all positive results should be returned.
- **What are the IDs of all trucks that have load capacity greater than 38?** Each value in the row storing the encrypted value of the truck load capacity must be *compared* to the number 38. Again the truck IDs of all positive results should be returned.
- **What is the total amount of load capacity currently available in Rome?** This query requires two steps. In the first step, each value in the row holding the truck position must be checked for equality again. In the second step, the truck load capacity should be *summed up* and returned.

So, different encryption algorithms with variable properties may be used for each column in the database to fulfil different functionalities. This selection may come along with a trade-off between functionality, complexity (in communicational and computational aspects), and data protection level. This fact is inevitable since the possibility to compare two ciphertexts reveals additional information about these encrypted data that are not revealed by randomized ciphertexts.

Furthermore, different users may have different permissions to view or edit specific datasets. Taken the example above, one may think of truck drivers, who can change only their own routes (and maybe view the others'), but a central organizing unit is permitted to view and edit all data in the database.

Due to these issues a configuration tool for the data-owner may be useful where she can define the desired minimal protection level and users' access rights for every column of the database. In addition, this tool may show the possible operations with the current setting or calculate the needed protection level for given query set.

4.2.2.2 Additional Business Applications

A lot of business applications need sensitive information and insist on communication between different business partners where this sensitive information is exchanged. As seen before, distrust is the main obstacle for joint computation of different participants in business environment. In this section, some secure applications are introduced which may be useful for the solution of business problems and therefore may be transferred into the cloud-computing setting. These presented applications are capacity allocation, e-auctions, election and secure collaborative planning, forecasting, and replenishment (CPFR) (based Atallah et al. 2003)

Auctions

The main goal of every participant in business applications is profit maximization. In most cases, these individual goals are in contrast of each other, since increasing profit of one participant goes along with decreasing profit of another participant. One quite easy way to agree upon a trade-off is using auctions.

In auctions, a set of N (potential) buyers (or bidders) and one seller agree on a price at which a product is to be sold. This can happen in different ways, e.g. auctions with non-discriminatory pricing and auctions with discriminatory pricing.

In e-auctions with non-discriminatory pricing every buyer has to pay the same price after the negotiation. Assume each buyer holds a pair *(p, q)* which states the price *p* at which a buyer is willing to buy amount *q* of the offered product. This pair is based on the demand curve of each buyer. On the other hand, the supplier has a supply curve that defines the price *p'* she should ask from the buyers according to the total amount of demanded products. To protect the privacy of the buyers, their demand curve is not revealed. Furthermore, the seller is allowed to learn the bidders' individual demand parameter only after her price *p'* is fixed. After the announcement of the (fixed) price *p'* only bidders with lower prices $p < p'$ are allowed not to buy, the other buyers are not allowed to alter their *q*.

In contrast, in e-auctions with discriminatory pricing, the price is not fixed, i.e. there are individual prices for every buyer. Here the seller computes her price *p'* in a way to maximize her revenue. A problem with this kind of auctions is the need for the buyers to reveal both *p* and *q* to the seller. However, this would compromise their demand curve. For that reason, Attalah et al. introduced a third party, called proxy, to perform auctions with discriminatory pricing in a secure manner.

Elections

In most business applications different participants have individual interests. These interests may be based on private information and stay in conflict. One way to solve these conflicts may be electronic voting.

Suppose there is a set of N voters that want to come to a compromise by using e-voting based on cloud-computing. The idea is to design a (verifiable) voting-system in a secure manner, for which the following holds:

- After giving his vote, the participant is not able to change or delete his vote. Moreover, he is not able to give multiple votes.

- No voter can send an invalid vote without being detected.
- The scheme provides privacy for all voters, i.e. nobody can learn anything about particular votes beside the information implied by the result.
- Correctness, i.e. the output after performing the e-voting describes the real result.
- The validity of the election should be checkable.

In theory, there are a few ways to solve this problem. For instance, Cramer et al. (1997) presented a scheme in “A secure and optimally efficient multi-authority election scheme” or Cohen and Fischer (1985) in “A Robust and Verifiable Cryptographically Secure Election Scheme”.

However, ways to transfer these schemes into the cloud and combine them with other business related applications in a secure manner have to be studied.

Collaborative planning, Forecasting and Replenishment

Other business applications, where participants take an advantage from taking part in joint computation are collaborative planning, forecasting and replenishment (CPFR). Like mentioned before, business partners, however, hesitate to provide sensitive data as input for the computation.

In the supplier-retailer supply-chain setting, this process is comprised of the following main steps:

- The retailer and the supplier input their (private) cost parameters.
- The retailer input (private) information, inventory status and backorders; the supplier inputs (private) information, inventory status and information about in-transit from supplier to retailer.
- Calculate forecast in a secure fashion.
- Compute the retailer’s and supplier’s optimal base stock levels.
- The retailer’s and supplier’s shipment quantities are computed based on the secret input given. Beside this information each participant learns nothing.
- Transfer payment from retailer to supplier is computed.

Attalah et al. (2003) provide a first analysis of CPFR as a secure computation problem. They assume a two-party scenario there and present a set of protocols to secure these computations against passive adversaries. Their presented protocols consist of different tools for SMC (e.g. secret sharing and homomorphic encryption) in different security models.

Capacity allocation

Suppose *N* retailers who sell products on non-competitive markets with linear demand curve. Furthermore, there is one central supplier with limited capacity *C*. The form of the demand curve is known by everyone (including the supplier) but each retailer’s market potential is kept as private information. In order to maximize its profit, every retailer wants to maximize his revenue. The supplier’s goal is the same, i.e. maximize her profit. This can be done in an optimal way if the supplier knows each retailer’s market potential. Since the retailers are not willing to reveal this information, the supplier tries to maximize her profit but has to deal with uncertainty.

Attalah et al. (2003) have presented two allocation policies to solve this business problem for multiple retailers but only one supplier: linear and proportional allocation. For both they presented protocol to perform these operations in a secure manner.

Summary

The presented applications offer several interesting examples of secure computation problems related to supply chains. Many approaches, however, consider a simpler scenario with single suppliers selling to a group of buyers or an abstract and simplified business or security model. Furthermore, transferring these applications into the cloud-based setting needs to be studied w.r.t. used parameters in practice, needed hardware and scalability in the multi-user setting.

4.2.2.3 Secure Linear Programming

The supply-chain master planning scenario and its corresponding model directly lead to a linear programming (LP) problem, whereas vector *c* represents the coefficients of the objective function, matrix *A* the restricting coefficients, vector *b* the values for the restrictions and vector *x* the variables.

$$\begin{array}{ll} \textit{minimize} & c^T \cdot x, \\ \textit{subject to} & A \cdot x = b, \quad x \geq 0 \end{array}$$

In order to meet the participants' requirements on privacy protection for inputs (i.e. *c*, *A* and *b*), the LP is solved in a secure fashion. This can be realized by applying SMC techniques. On the other hand, this approach results in increased computation and communication complexity.

In addition, the privacy level of input and output data may differ. Thus, applying the same level of protection to every input may lead to needless overhead. Instead, assigning a more adjusted level of protection is preferable due to its efficiency gains. Protecting publicly known data with the same default protection level to that for business vital data can be useless overhead. So it may be a possible spot for an additional efficiency gain.

By this motivation, the idea is to define a set of different protection levels. This allows an adequate privacy protection of input data while adding only the unavoidable amount of extra complexity in computation and communication by SMC.

A protection level itself represents a set of parameters, defining SMC properties. Differing parameters result in varying strength of protection and thus different computation and communication complexity. For instance, such SMC properties might be

- involved cryptographic tools (e.g. scrambled circuits, homomorphic encryption, secret sharing, etc.),
- parameters of the single cryptographic tools (e.g. concrete type or scheme, key length, etc.),
- type of security guarantee (e.g. information-theoretic, cryptographic, best-effort, etc.),
- number and type of adversaries to defend against.

Note that parameters may correlate partially. As an example, consider the type of adversary and cryptographic tools: for powerful adversaries the set cryptographic tools that defend against these attackers may be limited; on the other hand, more cryptographic tools are available to defend against less powerful adversaries.

With different identified levels of security needed, an appropriate number of protection levels should be defined, for instance in the scope of *top secret* to *unprotected*. These different protection levels need equal gaps with regard to decreasing protection strength and increasing complexity. This is an important fact in order to apply a scaled mapping.

Finally the mapping of protection levels to used cryptographic tools will be published between the participants of the secure LP computation. So, everybody knows which cryptographic technique is to be applied when processing data which has a certain protection level assigned.

4.3 Conclusion secure cloud collaboration

Cloud-computing offers great possibilities for centralized SCM approaches. With its characteristics, not only technical but also financial benefits are given. On technical side performance and flexibility can be increased, whereas on financial side savings in hardware and maintenance and staff lowers expenses and hence increases profit. However, data security and privacy is a major obstacle to implement these methods in practice. The fear of manipulation and spying by competitors or other (internal and external) attackers is too great.

With Secure Multiparty Computation modern cryptography offers tools to meet these concerns, but goes along with increasing computation and communication complexity. In addition, implementing a protocol for cloud-based SMC needs lot of know-how and background information.

Although there is a general approach for computing any function in a secure manner in theory, it is impractical in many cases. When the number of participants is too big, for example, the general approach needs way too much computation for it to be useful in practice. Another concern is complex functions which themselves need many computations. Evaluating those complex functions in a secure manner can be a resource intensive task. Hence it is very hard to create one tool that is set up once and has the ability to execute arbitrary computations. To implement SMC for different problem sets in real life, specialized protocols and well-defined assumptions and models are crucial. These assumptions imply a trade-off between security, complexity and functionality. However, given the right tools, it may be possible to collaborate cloud-based in a secure way.

Chapter 5 Obstacles and security requirements

5.1 Trust, incentives, data

Traditional supply chain tasks involving data sharing among collaborating parties are usually supported by integrated supply chain systems where complex interactions are established and finalized to the production of global master planning or scheduling of activities. It is well recognized that cooperation among trusting parties is recognized as a means to improve the efficiency of the supply chain, allowing the computation of the optimal working point of the chain, the reduction of the overall cost, and ensuring benefits for all the participants.

On the other side, parties in the supply chain are commonly reluctant to even partially disclose their sensitive data, that should be kept private in order to avoid any leakage among the other companies (who are potentially competitors). Furthermore, each actor could participate to the collaboration with its own goals, and if global optimization causes any reduction of their profit or missing their objectives, actors may be tempted to adopt a non-cooperative behavior, e.g. by altering the information provided to compute the global optimization, and have the coalition shifted to a situation more favorable to themselves. This conflict of interest and the resulting risk can be described as an information-sharing problem. In this context, risk can be evaluated as a function of the likelihood that some negative event, for example information disclosure or data loss, will occur and the expected consequences if it does occur, such as liability or penalties for noncompliance.

Moving supply chain management to the cloud complicates a bit the scenario, providing some advantages for the interoperability and efficient information sharing and exchange, but introducing some novel threats and vulnerabilities which have to be carefully analyzed. For example, some external actors are introduced in the interaction, e.g. the cloud provider, the cloud administrator, which could use their role to alter the exchanged information and threat the trustworthiness of the process.

To induce all the supply chain partners and the external actors to have a collaborative behavior, incentives schemes can be used to distribute risks, costs, and rewards for good behaving. Such schemes should take into account the cost-benefit scenario for attackers, since an attacker could attack only if the costs and potential loss are lower than the expected benefits. (as done in theoretical setting by “rational cryptography” and more recently in “rational protocol design” approach, where parties (or coalition of parties) are considered selfish agent trying to maximize their utility, and the protocol designer aims to prevent attackers from succeeding.(Garay et al, 2013).

5.2 Cloud computing and supply chain collaboration

This chapter will show why supply chain collaboration is well suited for a cloud-based implementation enriched with pressing security requirements. It will first describe the potential benefits of Collaborative Forecasting (CF) in the cloud, then the positive aspects of Vendor Managed Inventory (VMI) in the cloud and end with an overview of potential cloud-related risks and limitations of both concepts and the resulting security requirements. For a common understanding of the meaning of cloud computing, first a brief definition as given by the National Institute of Standards and Technology is quoted:

“Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell, Grance 2011, p. 2).

5.2.1 Benefits of supply chain cloud collaborative systems

5.2.1.1 Benefits of CF in the cloud

The most promising framework for CF might be an information hub as the model for information exchange combined with privacy-preserving protocols to compute the shared results. The information hub does not have to exist physically and can rather be seen as a logical entity (Lee, Whang 2000, p. 12). This model can eliminate the risk of information leakage through one of the partners or any third party: if the transaction protocols (e.g., based on secure multiparty computation) are set up properly and the original data can't be deduced from the processed results, the partners could benefit from the collaboration without giving up privacy of their data. There are several issues concerning the feasibility of such an implementation which have to be considered:

- Secure multiparty computation requires high computational power,
- Increasing or changing number of collaborating parties and increasing size of data base, i.e. need for scalability,
- Should be flexible enough to be usable in different collaborations,
- Reliable access to the results.

A cloud-based solution could tackle these points in many ways and would offer various advantages compared to traditional "on premises IT" (Marston et al. 2011, p. 178). In the context of CF the following three aspects are especially relevant:

(1) Cloud computing drastically reduces the cost for compute-intensive business analytics which were otherwise only available for the biggest companies which could afford to purchase and maintain the necessary capacities locally. The "shared pool of configurable computing resources" benefits from strong economies of scale achieved through the concentration of operations at large-scale data centers at low-cost locations and the much better utilization due to statistical balancing of demand from different users (Armbrust et al. 2010, p. 52). Thus, since secure multiparty computation requires high computational effort, the resources needed should be available at the minimum possible price.

(2) Cloud computing enables a high scalability of the provided services according to client demand with minimal service provider interaction. The client demand in the case of CF corresponds to the number of collaborating partners, the actual need for computing resources at a given time and the probably growing amount of data that has to be stored. E.g., if a collaborative forecast should be computed on a monthly basis, a cloud-based service could offer the required server capacity just for this certain time. It would not be necessary to maintain the probably then underutilized resources during the rest of the time.

(3) Marston et al. (2011) describe the cloud as "an adaptive infrastructure that can be shared by different users, each of whom might use it in very different ways." There are no restricting requirements to the local systems of the users as they just need a simple client (e.g. an internet browser) as an interface. Hence, the actual computing of the CF results is always performed on the standardized cloud servers; there is no need to adapt the core of the software to different platforms.

5.2.1.2 Benefits of VMI in the cloud

VMI partnerships can cause several benefits within the field of replenishment and forecasting. One key to its success is an effective and efficient connectivity between the customer and its vendor with the purpose of sharing the necessary information. This is realized as a rule with an appropriate and hence complex IT system. The development or solely the selection and implementation of such an IT system is an extensive, sometimes expensive and difficult task (Thome (2006), p. 155ff). According to Kuk (2004), small and medium-sized enterprises (SME's) benefit more from VMI than larger companies in a way that they perceive overall higher returns. One reason for that finding is that large companies already put huge effort into optimizing their replenishment processes. Another reason is the fact that the amount of data and information generated by large companies may exceed the capabilities of the VMI system (Kuk (2004), p. 645ff). Petersen et al. (2005) emphasize that a company which is seeking to expand the collaboration with its partners has to give close attention to the deployment and enhancement of linked IT systems and therefore may be forced to undertake remarkable initial investments (Petersen et al. (2005), p. 20). The problem here is that SME's which obviously could simply benefit from cooperation, are often reluctant to make large investments in the necessary IT systems to implement VMI, because risks are too large to them or budgets are not sufficient. Therefore (in addition to the points already mentioned in the CF section), cloud computing is an interesting option, since significantly lower initial investment is needed.

5.2.2 Risks and necessary security and process requirements

The same cloud-based solution presenting the mentioned benefits discussed previously present also some risks and limitations. These involve certain security and process requirements to fully exploit the potentials of collaborative supply chain concepts.

Table 5.1: Data leakage risks and related security requirements

Risk	Requirements
Inadequate data security	Secure computing protocols, also robust against inverse optimization Results protected against diffusion to not interested users
Unavailability of services	Strict service level agreements with cloud providers Avoid data transfer bottlenecks
Breach of internal or governmental data-protection rules or laws.	Rough control over data-storage location. Legal framework to deal with potentially inconsistent laws
Loss of potential benefits through lack of integration	Need for interface to other business planning tools

Dutta et al. (2013) point out that most important are risks that arise through inadequate data security which leads to imperilment of sensitive information. This is particularly the case where a not well-established, well defined secure cloud computing solution is in charge. Besides, even though the process itself might be theoretically secure, there could still be a possibility for one or more of the involved players to deduce the private input data of one of the others from the results and their own inputs. This is called 'inverse optimization' (Deshpande, Schwarz 2006, p. 5). According to Pibernik et al. (2011), a secure CF process should provide both: secure computation according to the foregoing definition and robustness against inverse optimization.

The loss of physical control over the data creates risks in two ways: the risk of unavailability and the risk of a potential breach of internal or governmental data protection rules. Firstly there is a dependency on the cloud providers and their abilities to maintain high service levels. Although these levels are fixed on relatively high standards in service level agreements (e.g. Amazon web services commits to an annual uptime percentage of 99.95%), the chance for unavailability might make some companies wary (Marston et al. 2011, p. 181). The performance of CF might also be limited by data transfer bottlenecks (Armbrust et al. 2010, p. 56). If huge amounts of near real-time data are used, limited bandwidths for the upload can slow down the process.

Secondly, cloud providers store the data where it is cheapest, which is in general not in the same country where the users are located. This might collide with the data-protection rules or laws which have to be complied. According to valid laws this can also be a problem if the data is only stored fully encrypted and can't be read without the necessary keys. This makes it necessary to carefully choose the cloud providers to obtain appropriate service level agreements and affirmations regarding the specific data-storage locations.

The implementation of a standalone forecasting solution might be relatively easy to deploy , but to unlock the full potentials of CF it would be necessary to integrate the results in other planning software. If this compatibility is not provided it could limit the benefits of a CF / VMI implementation.

5.3 Security requirements for the aeronautic application

Inter-organizational data sharing process is often hostile in aerospace supply chains since partners and suppliers are generally competitors: they can appropriate confidential information shared by partners not only to cooperate on the common program but also to enhance their competitiveness or to extend their position into the supply chain.
As said in Deshpande et al. study (2005), information sharing about inventory levels, order status, demand forecasts, production/delivery schedules and so on, contributes to increase supply chain performances. Unfortunately, companies don't share their "private" information due to the lack of trust for their supply chain partners, who could abuse of shared information in order to have all the benefits of information sharing.
Moreover, as the most of information shared in military aerospace are confidential and as many players produce both military and civil products, the concept of security takes a dominant role.

5.3.1 Cloud systems requirements

Cloud systems need of basic requirements in order to be used in the aerospace industry as they would be applied to carry out business processes and to manage highly sensitive data directly related to the business. Any cloud system has to be able to ensure the service continuity, to monitor users' behaviours, to protect data and the functionalities themselves from hazardous external attacks, to archive data for a very long period (data related to each part of an aircraft are kept for the their entire life cycle of the aircraft), and to have a space big enough to collect and manage a huge data quantity.

The Aerospace Industries Association of America (2012) defines the following minimal requirements for a cloud computing application:

- *Reliability of Service Requirements*: it is required an acceptable threshold level of service reliability from service provider;
- *Requirements for Tracking Sensitive and Restricted Documentation*: sensitive data and information (e.g., financial and customer information, intellectual property, design and operational data) must be secure and shared appropriately;
- *Encryption Requirements*: companies need their data are encrypted to a minimal acceptable standard, such as FIPS 140-2[30], during the data exchange process;
- *Long-Term Archival and Retrieval*: the time retention requirements for maintaining technical records and information demand a period exceeding the life of the platform with suitable archiving and recovery;
- *Storage Requirements*: the physical location of all elements of the cloud solution is fundamental.

All these requirements reflect the aerospace industry complexity in terms of need for a long and continuous time, confidentiality and size of data shared.

5.3.2 CPS security

The Cloud Planning System allows the aero engine overhaul supply chain to perform better its activities (times and costs optimization), but must preserve also the data shared from both external and corrupted parties attacks.

In the present discussion two scenarios will be considered. The first (scenario A) is a general case, where the CPS is provided by an IT service provider and then it is accessible from multiple actors belonging to different supply chains (Figure 5.1); the second one (scenario B) is more specific: the CPS service is provided by the MRO service provider to its supply chain partners (Figure 5.2), in this way also the requirement on the limitation to the location of stored data will be satisfied[31].

The parties involved in the scenario A are four:

- P1: Cloud Planning System (administrator);
- P2: Airline/Air force company;
- P3: MRO Service Provider;
- P4: Suppliers.

On the contrary, the parties involved in the scenario B are three since the Cloud Planning System and the MRO Service Provider are the same entity:

- P1/P3: Cloud Planning System/MRO Service Provider (administrator);
- P2: Airline/Air force company;
- P4: Suppliers.

The two potential scenarios differ only in the presence of an IT service provider. Such a business role is not diffused in the aeronautic supply chain as it introduces high risks that are out of control from the aeronautic firms: risks related to the data management, to the business continuity and to the correctness of results. Indeed data management is required to

[30] Federal Information Processing Standard publication 140-2 is a U.S. government computer security standard used to accredit cryptographic (Wikipedia, 4-03-2014).

[31] The management of aerospace and aeronautic data needs to respect storage limitations: due to laws imposing control and limitation in exportation and to the be stored in national location, the second case specially applicable for military aeronautic.

satisfy security requirements imposing to not share data with not authorized organizations or persons and to export data in other nations. Business continuity and correctness of results are two obvious requirements. As those risks and ICTs are very strategic for the aeronautic industry, outsourcing IT services is not so diffused. Anyway there are some cases, the most important is the Exostar, an IT service provider born as a joint venture of aeronautic firms[32].

In principal, the administrator of the CPS (the service provider) can be considered as a *semi-honest adversary*: it “correctly follows the protocol specification, yet may attempt to learn additional information by analyzing the transcript of messages received during the execution” (Aumann and Lindell, 2009) and makes use of the data against platform users. Actually, the service provider doesn’t participate in the plan computation but only furnishes the ICT resources (the hardware and software: the multiparty computation system) to the supply chain actors.

The supply chain participants (the airline or air force, the MRO service provider and its suppliers) are the actual users of the cloud planning system, they are required to provide their data in order the overhaul plan is computed. Their behaviour can be defined as *covert adversaries*: they “may deviate from steps of the protocol in an attempt to cheat, but such deviations are detected by honest parties with good probability” (Goyal et al., 2008); in other words, they can either put in the CPS not true data in order to improve their business position untruthfully, or attack the system aiming to acquire partners confidential data. Anyway, these events have low probability because, if detected, the business relationships will broken definitely.

In the B scenario, the MRO service provider is also the IT service provider toward its business partners, both the customers and the suppliers. This is possible because aeronautic firms owns very high IT competences. in this way, it reduces its risks but introduces higher risks for its partners: in principal the MRO service provider could attack the system itself to access confidential business data of its suppliers and of its customers or to correct results. In this case it can operates as a ‘malicious’ actor against its business partners and the probability to be detected are quite low.

In both the industrial scenarios, secure multiparty computation technology can be a valuable solution as it ensures the security of data shared in the system: input data are never decrypted in the cloud planning system and the output can be provided to who is actually interested to receive them.

[32] Currently the board of directors of Exostar is composed by 6 aeronautic industry representative and one independent (http://www.exostar.com/Board-of-Directors/)

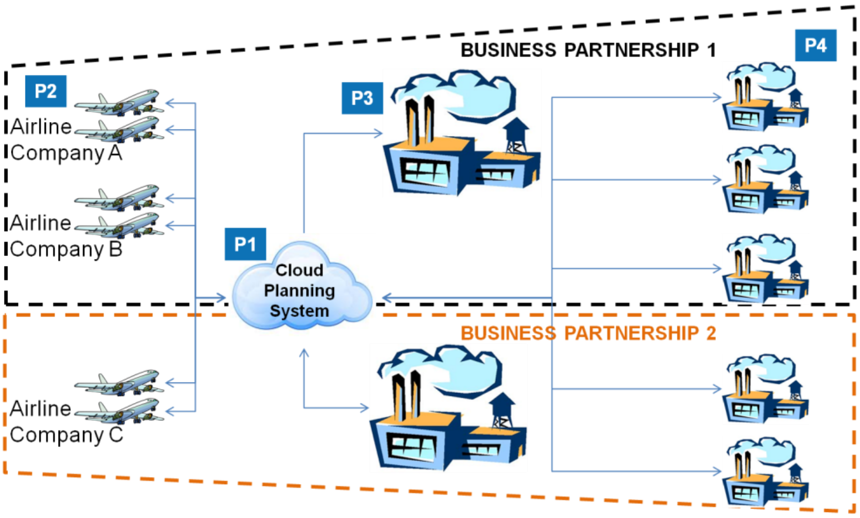


Figure 5.1: Aero engine fleet management: Scenario A. Source: Author's illustration

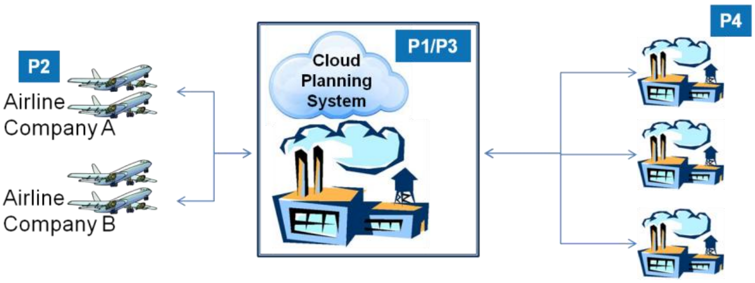


Figure 5.2: Aero engine fleet management: Scenario B. Source: Author's illustration

5.3.3 *Risks and impacts*

All parties in the CPS are subject to risks related to the possibility to have its own data attacked by third parties. As said before, the "attacker" wants or to seize the competitors' competitive advantage in order to win a better position in the industry (actors operating at the same supply chain level), or to know private information of actors that work in different supply chain levels in order to have more bargaining power.

Furthermore, in the general scenario, the risk to lose the uniqueness on its own data is higher than in the specific one, due to the number of parts that join the CPS: when there is an independent cloud-based platform (general scenario), it could be used by a wider community of players than when the platform is managed by the MRO service provider. In other words, the amount of risk is directly proportional to the number of parties using the CPS.

Now it is interesting to note that the data appropriation has a different negative impact for each party present in the CPS. The following Table 5.2 sums up the impacts on actors (Airline/Air force, MRO service provider and Supplier) who could lose their private data using the CPS, in terms of competitive advantage and bargaining power.

Table 5.2: Impacts on the CPS actors. Source: Author's illustration

	Airline/Air Force	MRO SP		Supplier		Admin
		Same sc	Other sc	Components manufacturer	MRO SP	
Airline/Air force data	Competitive advantage	Bargaining power	Bargaining power	Bargaining power	Bargaining power	Lost profit
MRO SP data	Bargaining power	/	Competitive advantage	Bargaining power	Competitive advantage + Bargaining power	Lost profit
Supplier data	Bargaining power on MRO SP	Bargaining power	Competitive advantage on other MRO SP + Bargaining power	Competitive advantage	Competitive advantage + Bargaining power	Lost profit

In general, when data are known by an actor operating at the same supply chain level, for example if airline company data are stolen by another airline company or if MRO service provider data are stolen by another MRO service provider or still when part supplier data are stolen by another part supplier, the impact on the "victim" is related to the loss of its competitive advantage in the industry. The victim, in fact, loses its sensitive information, such as competitive strategies in the workloads or warehouse management, which can be used by competitors in order to take more power in the related industry. In this case, the data confidentiality is essential to keep a competitive position. Besides, when data are known by an actor operating in a different supply chain level, for example if airline company data are stolen by a MRO service provider or by a supplier, the impact on the victim is linked to the reduction of its bargaining power. The attacker, in fact, will have information about the orders plan and the management of its partner and so it will be able to obtain more profitable conditions during future business relations.

In the Table 5.2, in order to consider a greater number of possible cases, MRO service providers and suppliers are considered in the following way: the former are divided in MRO service providers belonging to the same victim supply chain and to a different one; the latter are divided in suppliers that only realize components, and suppliers that provide MRO services as well as components.

At last, if data were known by the CPS administrator, the victim competitive position would be affected because of the administrator could share private data with the other actors in the CPS in exchange of economic benefits. The impacts on the victims change in relation to the attackers (if it is a direct competitor or a supply chain partner), as it has been said previously.

5.3.4 Data confidential level

An effective overhaul process requires the use and the access to several data packages owned by different partners. The Cloud Planning System, as designed in previous section, will homogeneously be able to manage all these data and to define the "best plan".

Now it is appropriate to summarize what type of data are shared in the CPS: the fleet owner (airline or air force) can provide engine work load data and other engine status data; the

MRO service provider can share its actual work plan and inventory status; and the supplier its production plan and inventory data. The system in return will be able to:

- Compute the schedule for servicing an engine (where the user is the engine owner) by accessing service provider work plan;
- Compute new works and supply plans, as well as to deliver orders and delivery timetables to the organization involved in the new plan;
- Update supply plans as new events (production delays, new priority MRO activities) are reported by the MRO service provider or suppliers;
- Reduce all kinds of leaks of private data toward other users.

All these data packages, input and output of the CPS, present different confidentiality values in relation to the type of information contained and to the party (P1, P2, P3, P4) which could steal them, for this reason it is required that the overhauling plan is presented only and limited to the involved partners, that is the engine owner and the service provider, while the suppliers have to receive only the purchasing order (if required). Indeed the overhauling plan is a sensitive data for the airline/air force because in that period it has to play its business role with some missing resources and is a sensitive data for the service provider because in that period part of its capacity is booked then is not available to other customers (in example that could need an urgent maintenance activity).

Chapter 6 Conclusions and outlook

The increasing competition in every mature industry is imposing to find out new sources of competitive advantage; one of them is the strengthening of business relationships between the actors involved in the same supply chain, who transform input in products and deliver value to the final customer/user. Business relationships are the channel through which data, information and goods are conveyed from a production stage to the next one. Making them more tied is about creating automatic procedures to exchange data, information and goods. Two or more partners (buyers/suppliers) collaborate if they define a process to exchange data in order to align their own production activities and to reduce as much as possible waste of time and resources.

In the aeronautic industry, a business scenario that is pressing for improving collaborative procedures is the after sale service, known as Maintenance, Repair and Overhaul (MRO) service. In particular, the engine MRO service was investigated. This process involves many actors: the owners of the engine (airline or air force), the MRO service providers (generally Original Equipment Manufacturers, OEMs, involved in the engine design and manufacturing business sector), and the suppliers of engine modules and components. A lot of data are shared in this supply chain in order to carry out the service, and this data flow strongly impacts on the service quality, in particular on the turn-around-time and on the total cost of the service. Currently these two aspects are inversely correlated: higher costs (mainly due to huge inventories and resources availability) are required for guaranteeing a shorter turn-around-time. Improvements in the data flow among partners are expected to reduce total service costs, through the reduction of inventories and a more effective use of the resources, without impacting on the service quality, or better still increasing it. Further, individual production decisions can be made globally more effective if sensitive data of other partners (customer, suppliers) are available.

The activities plan in the engine overhaul supply chain is a valuable process that will be positively affected by a data sharing: data and information on the engine usage patterns enable to forecast and then plan overhaul services with enough advance to organize the availability of the resources (parts to be changed, tools and machineries, staff). In other words, the data sharing process allows to arrange a more economic procurement plan by involving suppliers in parts production and/or in storing decision making. The section 3.2 shows execution practices of the current process and how higher collaboration level can impact on the individual production decision making.

In the consumer goods industry case instead, introducing a secure cloud planning system will enable a more efficient and quick data flow, the expected result is to increase the responsiveness of the entire supply chain and to optimize the distribution of resources and product into the whole Arcelik supply and customer network.

Collaborative forecasting and vendor management inventory are two methods whose effectiveness is widely accepted among academics and practitioners. However their application is not so diffused, firstly because the benefits provided are dependent on the supply chain features and are not distributed among partners, thus requiring to be supported by a benefits sharing strategy. Secondarily (and mainly) because these methods require confidential data to be shared with partners in order to compute the optimal individual production, storing and delivery plan; in this way each actor is exposed to threats from partners and from external attackers with the risk of being overcame by competitors. These collaborative methods are presented in the section 3.1.

While cloud systems are making shared collaborative environments more and more effective as they provide cost effective resources to every business actors independently on the technological capabilities, secure computation is introducing new privacy protection performances: a result can be the computation on encrypted data, that is without disclosing secrets to any other partners involved in the computation itself.

In order to design a Cloud Planning System, and in particular a system targeted on the aero engine overhaul service, both functional and security requirements are explained in the section 5 of this report. In general, it is recommended protection of individual data against any disclosure, availability of information on location of data, and high service levels. Such requirements are based on the analysis of the risks and the impacts that a breach of the system can entail on the data owners.

In the next period of the project, building on the results obtained, the following ones will be pursued:

1. An ad hoc supply chain model and the related planning algorithm will be developed in order to target the expected benefits for the aero engine MRO supply chain. The model and the algorithm will be able to:

- compute the best timeframe to remove the engine from aircraft and deliver it to the service provider for the needed overhaul service;
- plan service activities (at MRO service provider side) and parts production activities (at supplier side);
- control inventory status at every node of the supply chain.

2. A more detailed analysis of:

- how confidentiality of data and ‘not honest’ behaviours, even respect to colluding opportunities, can impact on the participation in collaborative planning systems;
- how to design a focused benefits sharing strategy to reduce risk of misbehaviour and increase acceptance of the shared system. The benefit sharing policy should make acceptable the risks run by each user from the participation in a shared environment and from the loss of a part of its own decision making authority. Moreover the benefit strategy have to take in consideration also user’s colluding probability.

3. A more detailed description of collaborative overhaul process, showing how data availability can change business and production decisions; in example, decisions on when the engine has to be serviced in order to reduce supply chain costs, or on, inventory replenishment policy, and so on. The functionalities of the system should enable such decisions and include cases in which automatic decision making system can be implemented by the users (in example, replenishment policies can introduce automatic delivery of purchasing orders).

Chapter 7 List of Abbreviations

AA	Aircraft Availability
AOG	Aircraft On Ground
ASN	Advanced Shipping Note
CAGR	Compound annual growth rate
CF	Collaborative Forecasting
CM	Condition Monitoring
CPFR	Collaborative Planning, Forecasting and Replenishment
CPFR	Collaborative Planning, Forecasting and Replenishment
CPS	Cloud Planning System
CR	Continuous Replenishment
CSN	Cycles Since New
CSSV	Cycles Since Last Shop Visit
DBS	Diffuser and Burner Section
DLSV	Date of Last Shop Visit
ECM	Engine Condition Monitoring
ECR	Efficient Consumer Response
EDI	Electronic Data Interchange
ERP	Enterprise resource planning
HSN	Hours Since New
HSSV	Hours Since Last Shop Visit
HT	Hard Time
ICT	Information and Communication Technology
IT	Information Technology

LLP	Life Limited Part
LP	Linear Programming
LRU	Line Replacement Unit
LSC	Life Support Cost
MG	Main Gearbox
MRO	Maintenance, Repair and Overhaul
OC	On Condition
OEM	Original Equipment Manufacturer
PLM	Product Lifecycle Management Systems
PMA	Parts Manufacturer Approval
PO	Purchase Order
POS	Point Of Sale
SC	Supply Chain
SCM	Supply Chain Management
SMC	Secure Multi-Party Computation
SME	Small Medium Enterprise
SV	Shop Visit
TAT	Turn Around Time
VMI	Vendor Managed Inventory
WIP	Work In Progress
WO	Work Orders

Chapter 8 Bibliography

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