Management Engineering Department

Master's thesis

Integrating logistics and production

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Date: 30 of June 2017

Abstract

The purpose of this research project is to help a supply chain manager to decision making easier in order to deliver final product on time to final customer. Coordination between all members of a supply chain are essential to achieve this objective and reduce bullwhip effect. The members considered on this thesis are going to be a manufacture, its supplier and supplier of that supplier (sub-supplier). A common purchase forecast is done thanks to Collaborative Planning Forecasting and Replenishment (CPFR) using an order point policy. A dashboard is elaborated with Key Performance Indicators (KPI) and graphics that shows the status of the supply chain. Then a simulation of a real case test how robust is the supply chain using normal random variables and evaluate how good and reliable are each of the members of the supply chain. At the end of the project there is a little experiment where a supply chain is checked with two different scenarios in which stability of demand are different. The results of that projects show an easy to use dashboard which evaluate a supply chain and its members and gives numerical and graphic information to the manager.

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1.Introduction

A supply chain is an entire network of entities, directly or indirectly interlinked and interdependent in serving the same consumer or customer. It comprises of vendors that supply raw material, producers who convert the material into products, warehouses that store, distribution centres that deliver to the retailers, and retailers who bring the product to the ultimate user. Supply chains underlie value-chains because, without them, no producer can give customers what they want, when and where they want, at the price they want. Producers compete only through their supply chains, and no degree of improvement at the producer's end can make up for the deficiencies in a supply chain which reduce the producer's ability to compete.

A supply chain management is basically about planning and controlling the activities of a company in order to secure that the right product is delivered in the right quantities to the right costumer at the right time to the right price. It is necessary for a company to have each step of that long chain as integrated and coordinated as possible.

A Just in time purchasing policy is generally the best choice to buy raw materials because it usually minimizes the total costs of total purchasing compared with Economic Order Quantity policy. Even though a Just in Time policy is the most efficient purchasing policy a priori not always can assure that will not break stock and it clashes with the idea of deliver product on time.

On the other hand, Economic order quantity policy (EOQ) depends on the policy of each member of the supply chain. Anyway, all purchase policy can fail if the forecasting of the manufacture doesn't take in account free production availability, production capacity or stock level of its supplier. So, in order to make an easier and common purchase policy, an order point purchase policy is going to be used in the whole supply chain.

Discoordination of each element of a supply chain that has optimized its stock level and its purchasing policy independently from other members is known as bullwhip effect. In other words, although your purchase forecasting is optimized, it can crash with the availability of the supplier in one specific moment on time line.

To mitigate this discoordination there is one possible solution that many companies have implemented and have shown to be very effective, the Collaborative Planning Forecasting and Replenishment (CPRF). This system implies the collaboration of each component of the supply chain on sharing its internal, confidential and sensitive information like demand forecasting, production capacity, production status, level stock…etc.

This solution has a difficulty to solve it because usually all suppliers tend to save all its internal information to avoid industrial espionage and to avoid lose competitiveness against its competitor. Nevertheless, each component of supply chain will have to construct trust relationships among them if they will want to survive in a long-term period, otherwise whole supply chain won't be able to satisfy the final costumer and won't survive against other competitors.

The idea is to create a common purchase forecasting in a month for manufacture, supplier and sub-supplier in a just in time policy, that guarantees that every member has an optimized

purchase policy that reduces the stock cost and, at the same time, guarantee that all production can be delivered at the right time.

It is entirely important for a supply chain to have a good coordination among each part that belongs to it. Regarding to suppliers it is especially important this coordination in order to reduce the bullwhip effect. For that reason, sharing information among these agents will be an essential task for the whole supply chain.

One of the biggest problems that a manufacture company can suffer in his business is not to be able to satisfy its client because it doesn't have product available in its stock. In this project, the idea is to face this problem attacking one of its root, the purchasing forecasting in a dashboard. The main goal of this project is to be able to assure customer receives his order in the agreed quantity and date.

A problem to control a supply chain is how to manage data extracted from production system and convert it to a useful and clear information for someone who must make decisions consequently. The more data received from a production system doesn't directly mean that a manager's will be able to take the proper decisions. The elaboration and presentation of that information will allow to a manager get the idea of what's happening, where is the source of the problem if exists and what responses are the most effective in a specific circumstance. A solution for this presentation of the information it's a dashboard where not only appear data from a supply chain but also it appears post processed and presented in diagrams, tables, schemes and KPI's (Key Performance Indicator).

The aim of this project is to create a dash board for a supply chain manager who wants to have under control all its parts. The objective is to gather all information in real time in one control panel that allows to a manager knows whether his production system will be able to deliver a purchase order on time and detect a problem before it occurs.

The reason of using a dashboard is to help supply chain managers to have all information in a way that makes it easier for them to make a better decision regarding the current state of the supply chain and the convenience of making a purchase order to a supplier in a specific time. If a manager receives information of his supply chain in a simply way it will be easier for him understanding the situation and taking a faster decision.

This dashboard would allow to manager to take structured and non-structured decisions. As an example of structured decision would be about the feasibility to accept or refuse a purchase order or knowing if one delivery will be on time or in case that this were not possible how much time of delay it would have. The information system gives the opportunity for a user to manage if it is necessary to change the order of the purchase order from their list of purchases made for its customers.

Summary of information in a control panel would be also a source of information for the process improvement department and open a door to detect which part of a supply chain are a bottle neck of the production system and where is necessary to put more effort on improve it. An integration of all this information in one information system would be a tool that may help on a better coordination of a supply chain and could detect its collapse before it occurs.

The Supply Chain Operations Reference model (SCOR) is the world's leading supply chain framework, linking business processes, performance metrics, practices and people skills into a unified structure. That model is a tool to represent, analyse and configure the Supply Chains.

The Model provides a unique framework that brings together Business Processes, Management Indicators, Best Practices and Technologies in a unified structure to support communication between Supply Chain Partners and improve the efficiency of Supply Chain Management (GSC) and the improvement of related activities of the Supply Chain (SC). The Model has been able to provide a basis for SC improvement in global projects as well as specific localized projects, including a homogeneous set of related processes.

The SCOR is a Reference Model that standardizes the terminology and processes of an SC for modelling, using KPIs (Key Performance Indicators), to compare and analyse different alternatives and strategies of SC entities and of the whole SC.

The SCOR model allows to describe the business activities necessary to satisfy customer demand, and is organized around five Main Processes of Management: Planning, Source, Manufacturing, Deliver, and Return.

2. Problem situation

The problem that is set out in this project is to create a dashboard among a sub-supplier, a supplier and a manufacturer. It will be constructed with information supplied by both parts so that It will mean that collaboration is essential in order to get an information resource for both. The coordination of every entity will be determined by the decisions made on the basis of that panel, so in case of incoordination it will be easier for both managers to detect and discuss what decisions has been done wrongly and what kind of corrective measures have to be taken to avoid it.

The dashboard will be created on costumer direction, that it means that the main goal is final client satisfaction through a deliver on time. Both companies will have the same information to take decisions to satisfy the final client.

The KPIs in the dashboard will be based on SCOR (Supply Chain Operations Reference Model). This KPIs must help supplier and manufacturer to organise themselves around the five main processes of management: planning, source, manufacturing, deliver and return.

When an order is placed at a producer and the producer has to give a specific delivery time he needs to be sure that his suppliers can deliver at the right time. If the promised delivery time is exceeded the producer will often pay a fee. A dashboard will support the producer in making his decision.

2.1. Problem statement

"How can dashboard be designed for a supply chain?"

In order to design a dashboard, different indicators need to be identified together with the interrelationship between them. Also, the significant indicators (KPI) needs to be identified as they will be presented at the dashboard.
Supplement questions could therefore be,

- How can the different indicators be identified?
- Can the different indicators be grouped?
- What is the relation between the indicators?
- What is the significant indicators?
- How can they be presented on a dashboard?
- How can the dashboard be maintained?

3. Literature review

This theory section contains review and description of various literature of purchase management, supply chain management, dashboards, supplier collaboration or CPFR (Collaborative Planning Forecasting and Replenishment), supplier evaluation and stock control.

Related to the concepts above, I will proceed to explain each of them for a previous better understanding. Supply chain will be described as a set of members that need to be coordinated in order to achieve a main goal. The main goal is to deliver the final product to the final costumer at the right time. After that, an overview about how a dashboard with processed information can help a manager to take the proper decision at the proper time. Afterwards, the CPFR will be presented as the essential tool to develop the idea for coordinating and improving the whole supply chain, and to minimise the total product costs. At the end of section I will show how stock control can help for making the supply chain more efficient and less expensive at the same time.

3.1. Integrated supply chain and purchase management

When a product order takes place at the producer, and the producer must give a specific delivery time, he needs to make sure that his suppliers can deliver it at the right time. If the pointed delivery time is exceeded the producer will normally pay a fee.

One of the problems that a manufacture must afford for being successful is the Purchase Management. Therefore, if raw materials don't arrive on time, the supply chain and the client's satisfaction may be in risk of breaking up, and it could turn into sales loses for the company.

(Jahnukainen & Lahti, 1999) says that *"The efficiency on purchase area determine the price of a product directly"* and demonstrates the proved background that *"a supply chain may perform unsatisfactorily although the individual units in the chain are performing well"*. Therefore, he gives three viable solutions. To control the suppliers as if they were our own manufacture, having special arrangements for critical components, and the integration and cooperation of members of a supply chain.

Keeping all this inputs in mind, the objective of this project is to convert these three purchase areas: manufacture, supplier and sub-supplier, into a unique centralised purchase forecasting program on a simple dashboard. The integration and cooperation on forecasting purchase orders will be the main point of this project, so I will treat the supplier's forecasting as ours.

The economic lot size policy based on JIT, developed by (Yang, Wee, & Yang, 2007), state that for an integrated buyer-vendor system, the inventory cost and the reply time of an order must be reduced.

(Rau & OuYang, 2008) developed a model of purchasing based on a *"just at time"* acquisition of raw materials. This model proposes a single buyer - single vendor relation at a restricted amount of time system. It also shows how the delivery time might be affected by the model.

The model succeeds by minimizing the shared total costs incurred by the vendor and the buyer, and prove the optimal way to perform to achieve a linear increasing or decreasing demand solution.

It also shows that the performance of the integrated consideration is better than the performance of any independent decision made by either, the buyer or the vendor.

JIT purchase policy is usually the best policy to minimize purchasing costs and to optimize the stock level. However, (Wu, 2007) has demonstrated that JIT system is not always better regarding cost effectiveness than EOQ (Economic Order Quantity). Despite, EOQ could be better than JIT in some specific cases.

3.2. Dashboard

The reason for constructing a dashboard for a purchase forecasting is to have all the information of the supply chain summarised just in one panel. It also provides managers with a view of your current status, so you can anticipate the worst scenarios and perform to succeed.

The use of appropriate indicators can help the managers to be more responsive to the dashboard signals. The OEE monitoring in manufacturing plants is discussed by (Anand, 2010) stating that *"Faster response can reduce machine downtime; improve machine performance and overall plant efficiency"*. For that reason, not always the data presented by itself can help to a manager, so KPIs could help to take faster decisions.

(El Farouk Imane, Foaud, & Abdennebi, 2017) present a methodology called OPRI (Objectives, Parameters, Risk, Indicators) to build a medicine supply chain dashboard for public hospitals. This methodology is based on process modelling using SCOR (Supply Chain Operations Reference), ARIS and risk analysis.

(Franceschini & Turina, 2012) propose a methodology that show how to merge the existing Performance Measurement System to define a unique shared reference system and provide a general performance dashboard in order to monitor WaSCs (Water and Sewage Companies).
It is developed in order to assist regulators with a small set of critical indicators (performance dashboard) for the evaluation and monitorization of the service.

(Goh et al., 2013) propose a real-time risk monitoring based on real-time data collection and analysis. The Risk Vis is based on multi-hierarchy modular design. It helps to monitor and collect real-time risky information that contains both internal and external manufacture data.

This information may help the managers to make better and safer decisions in order to avoid the break of the supply chain if any unexpected event happens.

Regarding that, it would be kept in mind that suppliers are usually supplied by another sub-supplier. That means that if there happen any unexpected event or issue in any of the steps of this chain, all the chain will be affected, and consequently it would affect the customer's delivery time directly with all their consequences.

The article of (Karr, 2012) has shown that those who are engaged in collaboration with a supplier will be rewarded with superior profits and stronger relationships, which are critical to the market success and for having a growing platform. It says that dashboards are essential not just for the manufacture, but for the suppliers. The dashboard should be created in collaboration between the supplier and the buyer for the best effectiveness. The importance of having the right and common metrics for both determines the relationship between the buyer and the supplier. "*Dashboards work best if there is senior management support for a customer-supplier relationship process that uses relationship and strategic performance dashboards".* That proves that forecasting of purchasing must be done by a buyer-supplier collaboration.

A very accurate example of a good dashboard based on the SCOR model is shown by (Pretorius, Ruthven, & Von Leipzig, 2013) applied to an egg producer placed in South Africa which captures the trend of the different performance attributes of the supply chain.

The model serves to facilitate the transition from local and functional management control to a wide supply chain management participation and approach before engaging it in a full-scale SCOR implementation. The way this article presents the results using both KPI's and graphics, will be used in this project to show the data and results in our dashboard at the most effortless way.

The United Nations World Food Program's Supply Chain Management Dashboard, as known as SCM-D, is described by (Sithole, Silva, & Kavelj, 2016). One of the objectives and values of that organization is to ensure a zero-hunger world society. Its work is founded by three pillars: to increase operational efficiency and effectiveness by enhancing the supply chain visibility; to finance the organisation through donation founds; and to provide overall services to those in need.

(Strandhagen & Dreyer, 2006) present the concept of an ICT based supply chain dashboard. It may benefit to get access to a real-time monitoring facilities, to speed up recognition and to an integrated decision making. All those inputs give a true value supply chain perspective.

3.3. CPFR (Collaborative Planning Forecasting Replenishment)

As we already know, bullwhip effect is the result of a discoordination of each component in a supply chain which has optimized its stock level and its purchasing policy independently from the other members. Discoordination may become bigger when the supply chain becomes longer and other entities are added into the chain: that increases the problem's complexity.

Many methods and projects have appeared in order to mitigate this effect between a supplier and a manufacture. One of these is CPFR, where manufacture and suppliers work together to get a better synergy. CPFR is a management process in which supply chain participants collaborate in the preparation of sales forecasts and replenishment plans for greater visibility. This process improves the synchronization of the actions related to the sales forecast and the planning of the supplies for all the participants. It allows to reduce the level of stocks and improve the rate service towards the final customer.

The objective of (A. Kubde, 2012) is to shed light on the collaborative relationships between buyers and sellers and its impact on supply chain performance. It explores the domain of CPRF for optimizing supply chain performance. In addition, it says that in the future all companies will must adopt any kind of partnerships initiative with suppliers. The bullwhip effect can be reduced with information sharing and demand forecasting between the supplier and the buyer.

As (Ji & Liu, 2010) state, CPFR emphasize on the importance of the cooperation and partnership theory regarding the supply chain strategies, but theoretically the application process is not as satisfactory as it is forecasted.

Regarding this problem, demand is not having that importance yet, so there aren't still very clear solutions for sales and orders forecast steps. In a short-term future, CPFR model is going to be used by a lot of companies in order to cover their own needs.

(Kreng & Chen, 2017) apply a three-echelon supply chain between manufacturer, delivery centre and retailer focused on the order quantity, shipment sizes and number of shipments.

The results of the study state that compared with a typical delivery policy, all supply chain stages collaboration and the agreement of applying the optimal shipping size will totally improve the cost reduction.

(J. T. Lin, Chang, Chen, & Xin, 2003) study the KPI flow and data flow from CPFR system, applied to the relationship between two Taiwan companies. Once you implement CPFR system, CMC

and the buyer may collaborate planning, forecasting and refilling according to the forecasted demand.

Besides, in the CPFR system, seller and buyer may solve exceptions in collaboration. Consequently, buyer and seller may collaborate in planning, forecasting and refilling according to the forecasted demand.

The article also analyses the CPFR related information system for designing a better KPI information flow. In that case, there are four KPI used: order forecast accuracy, finished goods production lead-time, on time delivery and order fill rate. A successful KPI flow design may show the improving performance to facilitate efficiency in supply chain.

Applying CPFR system into a company is not as easy as it seems to be. It requires a business processes change, as well as an inward change focusing into a broad multi-enterprise point of view.

(Kubde & Bansod, 2010) suggest to the managers to investigate about the reasons for why, what and how to manage in order to select the most appropriate decision for CPFR system. In addition, in the study they ask you to call into question the theory and research practise in order to find which are all the different CPFR activities. Finally, it concludes stating that in a short-term future all organizations would adopt CPFR system.

3.4. Supplier evaluation

To manage, control and evaluate a whole supply chain starting with the sub supplier, continuing with the supplier and finishing with the manufacturer is an idea that it's applied in this project, and have had few precedents in other literatures.

Supplier evaluation based on KPI is a common practise in many supply chains. That helps to evaluate suppliers and its efficiency. Although this evaluation is based in historical data, it isn't always the best resource to evaluate a supplier in a specific period of time.

Knowing that a manufacture has a variety of different suppliers for each component it's also important to evaluate them in order to know which one is the most appropriate for a specific command.

In this thesis project, the most relevant KPI item will be the delivery time, because the main objective of the project is to make a forecast purchases' dashboard without failing on delivery time. Of course, it will take also into account some other KPIs as reliability, cost, etc.
When a purchased order is placed or forecasted sometimes the regular supplier responsible of bringing the raw material to the buyer is not working as usual. There are two possible reasons.

Because the supplier may have a too large demand, or because supplier might have some internal problems that doesn't allow it. On the other hand, that might happen because of some internal problems and is not the most appropriate moment to send a purchase order in spite of is the one that normally works better.

(Bai & Sarkis, 2014) use DEA (Data Envelopment Analysis) as a comparative analysis to identify sustainable supply chain KPI that could be used for a sustainable performance evaluation for suppliers.

"Sustainability performance evaluation can be eased for managers by using KPIs, and then use these KPIs to develop an easy and comparable performance measure". It reinforces the idea of comparative analysis between suppliers, so it means that before to forecast or to launch a purchase order is a good idea to check which supplier is more suitable at a certain moment.

(Li, Lim, Chen, & Tan, 2016) examines existing approaches for supplier selection focused on its advantages and limitations. The paper proposes an approach for supplier selection based on selection criteria and Agent-Based Simulation (ABS) to address some of the limitations. The proposed approach can be used to produce feasible supplier selection decisions which need to consider multiple criteria and uncertainties. To do that could be difficult to be handled by the traditional mathematic approaches. Those experiments show that the proposed approach can be used for supplier selection through quantitative evaluation of the supplier profiles.

The selection and evaluation method for suppliers that (Pal & Kumar, 2008) uses for expensive procurements provides a logical framework for supplier management based on Security, Quality, Deliver and Cost. It transforms this items to a "Vendor Performance Dashboard" for decision making.

The idea of (Pradhan & Routroy, 2014) was to identify the critical success factors and its corresponding KPIs using the AHP. That can evaluate the performance of supplier development that allows to get an approach for quantifying, monitoring, analysing and evaluating the success of the SD programme.

"Supplier evaluation and selection must be systematically considered from the decision makers" say (Xia & Lim, 2008), whose supplier selection method allows to reflect the supply chain strategies of suppliers. Unlike other methods just can include quantitative factors, this method allows qualitative factors as well.

(Ying, Lijun, & Wei, 2009) proposes some keys for establishing KPI to reflect supply chain operations, and say that *"By providing a simplified assessment of real-time supply chain performance, dashboards change the speed and method in which executives enhance supply chain execution"*.

3.5. Stock control

Stock level is a crucial factor that help to a manufacture be successful for a specific delivery time, the more stock levels a manufacture the less probability will have to fail if an unexpected rise of demand appears. However, an increase of stock level usually involves of an increase level of cost and decreased competitiveness in the company.

(Kang & Kim, 2010) presented a model for a supplier to control the inventory of its customer through a vendor management inventory (VMI) that integers inventory replenishment and deliver planning in an optimized way.

The purpose of (Y. C. E. Lin, 2006) is to explore the experience and results of companies that manage logistics services to their chain convenience stores and their suppliers. It concludes saying that the most crucial factor is an effective supply chain: *"An efficient supply chain system using e-Logistics is built on effective communication between stake holders"*.

As (Raghavan, 2002) says, the aim of a supply chain is to produce and sell the desired products in the proper delivery time, and studies some random network modelling techniques for analysing supply chain net- works. This study allows to compute lead times and to rely on every facility of the chain.

(Zimmer, 2002) evaluates two situations of a supplier and a producer in a "just in time" environment where the capacity of supplier is uncertain. In the first situation, they both don't share information, however on the second one they do. In that second case, it's created a coordination system for a centralised and non-centralised planner. It shows that in both cases the two costs can be equally low. It also leaves one research field opened to include another step in the supply chain for the future. That is what it's being partially done in that thesis.

4. Analysis

4.1. Necessary information for controlling a supply chain

The objective of gathering information needs a reflection of what kind of information it is necessary to don't fail in the agreed delivery date, starting from suppliers and their suppliers, the several types of transport used with raw materials and the final deliver:
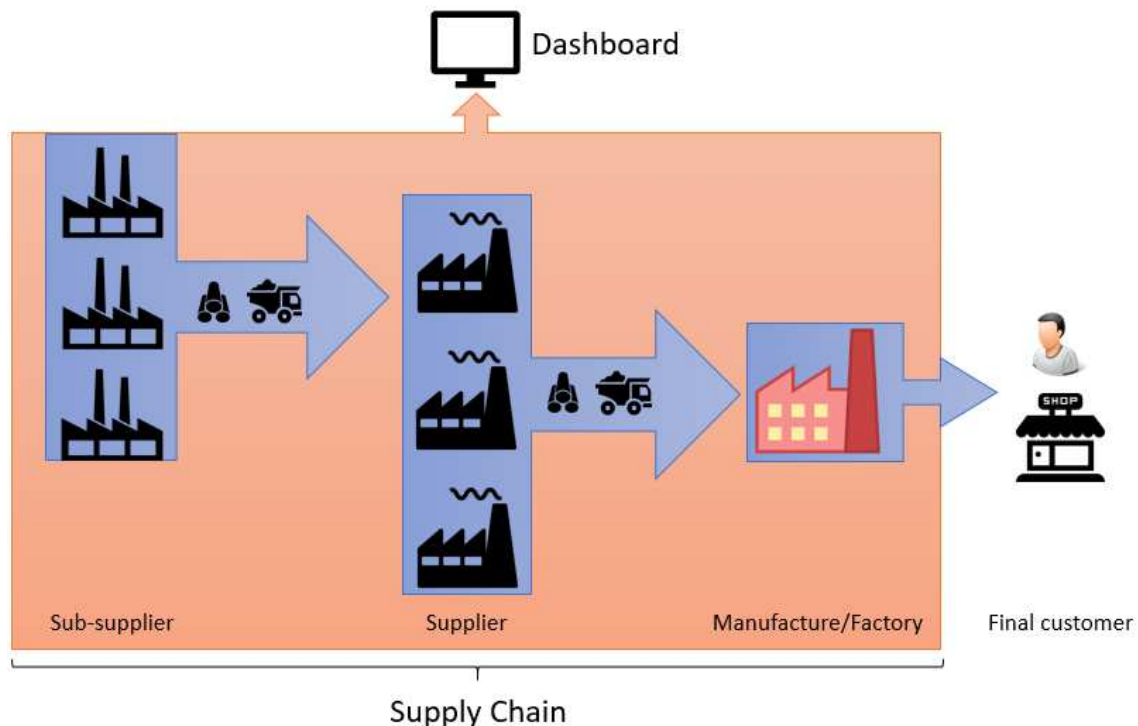
Figure 1. Supply chain dashboard

4.1.1. Manufacture or supplier

An interchange of information with suppliers is crucial to create a good coordination of all the system production and to decrease or eliminate the bullwhip effect. Moreover, the whole supplier network has directly or indirectly impact on the provisioning of our production system, this includes not only our direct suppliers but also suppliers of suppliers.

Hereinafter it is shown the essential information that members of supply chain should share:

Production of normal capacity (units / day)

It is essential for knowing how much workload it can be requested in a period. It is an information that is important for selecting the main providers of a supply chain. If production of normal capacity is too low the chain will be in risk of collapsing and suffer delay.

Maximum capacity of production (units / day)

In peak working periods is necessary to know how far the production system that one manage can support. It is important not only for accept or refuse an order from a customer but also for controlling costs.

Status of capacity in real time (units /day)

Must be kept in mind that the provider may not be working for just one customer, probably will have more than one and its capacity will be fluctuating constantly whenever they receive purchase orders from its customer portfolio. So, considering the status of capacity of suppliers is necessary to know when and how much it is possible to request raw materials at some time.

Reliability Factory (probability that stops the production system) (%)

Uncertainty of the events that surround us is a probability that must be considered. There are many factors that could interrupt our manufacturing system, i.e. break of a machine, electric cut, fire…etc. The problem lies in its measurement and its certainty, so a good way to know it would be based on the historical database. Instructions from the machine manufacturer that has provided machines of the system production can help to calculate this percentage.

Purchase order initiated (units)

The work in progress in a factory at some point can determine the speed that a new purchase order can be done. Work in progress can be an obstacle for the flow of a supply chain.

Purchase order without being initiated (units)

In most cases the providers will have a list of purchase orders from many costumers, this can make a delay on the delivery. The amount of purchase orders that one has in its own system is something that one can manage and order depending on hurry of each order.

Stock of raw materials of each component at real time (units)

Availability of raw materials will mark the efficacy of suppliers; this data can suppose the impossibility or the feasibility to make a purchase order and have its quick response. The fact that a production system can produce something reactively will be related with the amount of stock that one has in its factory at some point.

Stock of finished product in warehouse and security stock level (units)

Level of stock of finished production is a positive indicator for controlling a supply chain, the more finished production has in its possession, the more guarantees a supply chain will have for receiving ware at time. However, it affects to the storage cost.

Capacity to store finished product (units)

Capacity of warehouse can be a bottle neck on a supply chain flow and can determine total cost and capability for having a security stock reserved for a rising demand. The capacity of a warehouse determines how much stock someone can have in his factory. It is also important to manage and planning transport to the final costumer, so the less capacity of a warehouse can involve make trips more often.

Capacity to store raw material (units)

As well as finished production warehouse, raw materials warehouse can be bottle neck if there are not space enough. The warehouse capacity of raw materials will establish the amount of production that a production system can assume. It also will be a fundamental data in order to manage purchases and transports from purchasing area.

Demand forecasting based on historical information demand period (units/period)

Demand forecasting is essential when someone is planning purchase orders. Demand determines the production of a factory, and consequently affects into its purchase management and into purchase management of its customer. Share demand planning bring an opportunity to manage purchases and decide if it is better to advance or delay them.

Percentage of defective raw materials (%)

Not all the raw materials received from suppliers satisfies the quality required from a purchaser and must be a latent problem if it is not considered. As the reliability factory, percentage of defective raw materials and defective units produced is difficult to measure and must be measured by historical database.

Percentage of defective units produced (%)

Inevitably not all the production made by factory meets quality requirements, and not all production can be served to clients with guarantees, therefore it is included this percentage on the dashboard developing.

Number of suppliers that supplier has (units)

Complexity of supplier's network makes more difficult the control of supply chain and is important to have it under consideration.

Distance from supplier to factory (kilometre)

Proximity of suppliers determines the purchase planning and the costs related to that. It is also important for knowing the quantity requested in every purchase order.

Number of units of products demanded by client (units)

It is the amount of product that a costumer has requested and the departure data that it has planned on this project.

Agreed delivery date (time)

It is obvious that if someone is trying to prepare a delivery on time first of all needs to know how much time is available to do it.

MRP product that we manufacture (units)

The complexity of different pieces that needs to be made will establish the complexity in number of suppliers that a supply chain needs.

4.1.4. Customer

The last part of a supply chain is the costumer and the one that in this project needs be satisfied on arriving.

Distance between our factory and the customer (km)

The further the final costumer is the more time it will takes for deliver.

Agreed delivery date (t)

It is the data who set deadlines and the departure data for an operative management of a company.

Information used for this project			
Necessary information for a PFCR	Supplier	Factory	Customer
Production of normal capacity (units / day)	✘	✘	✘
Maximum capacity of production (units / day)	✔	✔	✘
Status of capacity in real time (units /day)	✘	✘	✘
Reliability Factory (probability that stops the production system) (%)	✘	✘	✘
Purchase order initiated (units)	✘	✘	✘
Purchase order without being initiated (units)	✘	✘	✘
Stock of raw material of each component at real time (units)	✔	✔	✘
Stock of finished product in the warehouse and security stock level (units)	✔	✔	✘
Capacity to store finished product (units)	✘	✘	✘
Capacity to store raw material (units)	✘	✘	✘
Demand forecasting based on historical information demand period (units/period)	✔	✔	✘
Percentage of defective raw materials (%)	✘	✘	✘
Percentage of defective units produced (%)	✘	✘	✘
Number of suppliers that our supplier has (units)	✘	✘	✘
Distance from supplier to factory (kilometre)	✘	✘	✘
Agreed delivery date (t)	✔	✔	✔
Number of units of products demanded by client (units)	✔	✔	✔
MRP product that we manufacture (units)	✘	✘	✘

Table 1. Information used for this project

4.1.3. Transport

Another valuable information for a supply chain that should be considered would be about transport. However, transport is not going to be included in the model developed in that project.

Depending on the complexity of the MRP of the product and the kind of product that is being manufactured the time of transport may have a relevant role in a whole supply chain. The distance and the diverse ways of transport are also factors that affects to a supply chain directly.

Above it is presented the most relevant data that should be considered:

Average time from ordering the transport to the beginning of the transport (t)

It is the time that it takes for example to arrive from the moment you give the order until it arrives. Normally transport is outsourced so this is an important to keep in mind.

Maximum time from ordering the transport to the beginning of the transport (t)

The maximum time from ordering a carriage until it arrives can be very damaging in terms of timeliness.

Average time it takes the carrier to bring the raw material warehouse of a vendor to our factory (t)

This include the time of response of a supplier takes to bring the raw material.

Likelihood of suffering a delay transport (accident, traffic, weather conditions ... etc) (%)

The uncertainty of the transport conditions or even the total loss of goods.

Average time delay that the transport can suffer (time)

The transport can suffer delay because of wheatear, mechanical problems, etc.

Number of transport used in transport (train, boat, plane, truck, pipeline, etc ...) (t)

The more ways transport it is being used both for supplies and for delivery the more complexity will be the whole transport.

Speed of the transport media (Km/h)

This data will determine how fast the goods will arrive to its destination.

4.2. Methodology

4.2.1. Limitations:

The method to ensure that suppliers are not going to fail on its delivery time that this project is going to follow is start thinking that all demand of our suppliers that does not come from our manufacture has preference regarding our demand. It means that if supplier must choose between satisfy our demand or satisfy another customer demand, the supplier will always choose to satisfy the other customer. For example, if a supplier has a capacity to produce of seventy units per day and has a demand of fifty units of another customer and fifty units of our manufacture, then the supplier will deliver fifty units to the other customer and twenty units to our manufacture. Of course, this methodology does not follow a real situation, but in this project the goal is to ensure delivering the production at the right time, so the methodology includes the worst possible scenario.

1st: Manufature forecast:

Based on manufacture demand, the purchase predicted is calculated.

2nd: Supplier forecast:

Based on supplier and manufacture needs, the purchase predicted is calculated.

3rd: Sub-supplier forecast:

Based on sub-supplier and supplier needs, the purchase predicted is calculated.

6th: Manufacturer simulation:

It simulates a real situation through random variables based on manufacture forecast and supplier simulation.

5th:Supplier simulation:

It simulates a real situation through random variables based on supplier forecast and sub-supplier simulation.

4th:Sub-supplier simulation:

It simulates a real situation through random variables based on sub-supplier forecast.

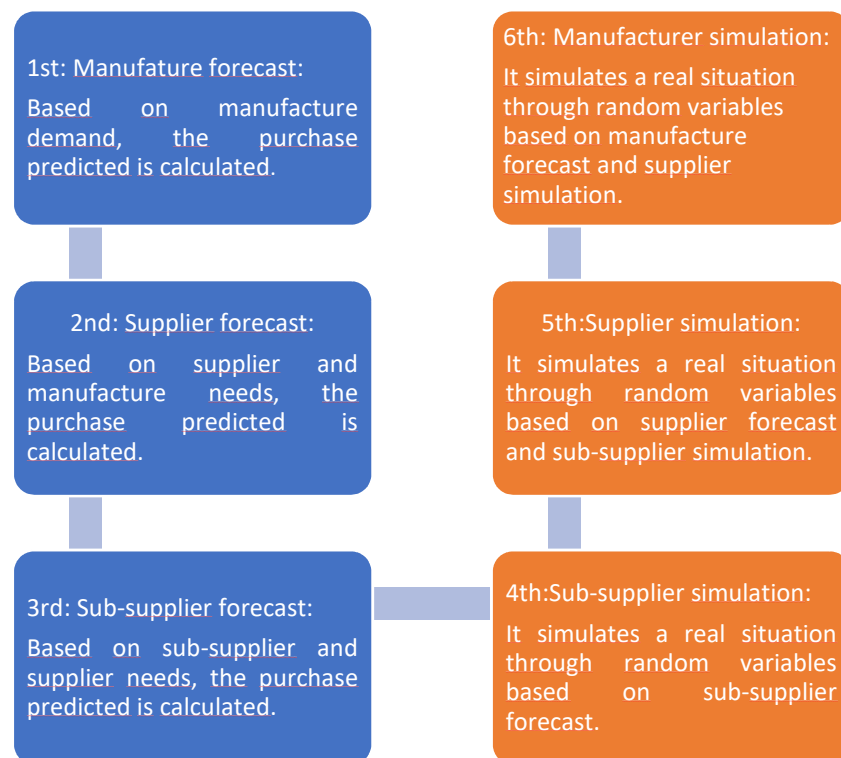*Figure 2. Calculation steps of the tool*

4.2.2. Considerations:

·All product elaborated on the method needs one unit of raw material to produce one unit of finished product.

·The shared predicted demand of supplier and sub-supplier are considered constant during the whole month.

·It's assumed that production capacity of each member of the supply chain is constant during the whole month.

·The transport time from each member is considered one day as a fixed variable.

·A provider only sends its ware if all lot of product Q_i is completed.

· There is no limit on warehousing of finished goods or raw materials in any of the three members of the supply chain.

4.2.3. Nomenclature

$T = \{1, \dots, 30\}$	All days of the month
t	Specific day of the month
$i = \{1,2,3\}$	Manufacture, supplier, sub-supplier
j	Number of purchase order
$J = \{1,2,3, \dots, 30\}$	All purchase orders
Q_{ij}^t	Purchase lot size of i expected to receive it on day t.
$\tilde{Q}_{ij}^t$	Purchase lot size of i received on day t.
$q_{i,j}^t$	Quantity predicted produced at day t for a member of the supply chain i.
$\Delta_{i,j}^t$	Accumulation of product produced at day t for a member of the supply chain i.
R_i	Order point
I_i	Security Stock
$D_i^t = d_{i,}^t + q_i^t$	Total month predicted demand for element i.
d_i^t	Demand in a specific day from other costumers
RM_i^t	Raw materials stock level on a specific day
FG_i^t	Finished goods stock level on a specific day
C_i	Maximum capacity of production
RD_i^t	Real monthly demand for element i.
W_i^t	What should be produced every day for element i.
P_i^t	Real production of element i.
$\Delta \delta_{i,j}^t$	Accumulation of product produced for the supply chain.
L_i	Launch purchase order cost

c_k	Cost of possess a unit of product for one day
c_h	Cost for deliver a product one day late
c_u	Cost of one raw material unit

4.2.4. Initial data

To begin with the excel program it is necessary to introduce the initial data first for each element of the supply chain:

C_i	Maximum capacity of production (units/day)
R_i	Order point (units)
Q_{ij}^t	Purchase lot size (units/lot)
RM_i^0	Raw materials stock level at the beginning of the month (units)
I_i	Security Stock (units)
L_i	Launch purchase order cost (DKK)
d_i^t	Daily Demand (units/day)
c_k	Cost of possess a unit of product for one day (DKK/day)
c_h	Cost for deliver a product one day late (DKK/day)
c_u	Cost of one raw material unit (DKK/unit)

Production capacity	1600	units/day
Order point	1600	units
Purchase order lot	5000	units/lot
Initial stock of raw material	2000	units
Security stock	100	units
Launch purchase order cost	700	DKK
Daily demand	1000	units/day
Cost of ownership	7	DKK
Cost of deferring demand	21	DKK
Purchase unit cost	2	DKK

Table 2. Example of data entry box

4.2.5. Order point purchase forecasting policy

The method selected in that thesis for doing a common purchase policy is order point purchase, (Federgruen & Zheng, 1992) and (Schneider, 1978) developed it more deeply. Order point policy mean that stock level cannot be under a certain value R_1. When the raw materials level reach that point, then a new purchase order must arrive that day.

Manufacture

The starting point for forecasting purchase on this project is based on the month demand of a factory. This demand will affect directly on purchase orders made to suppliers because when stock level reach less than security stock R_1 then is expected to receive materials from a purchase order from supplier.

If

$$RM_1^{t-1} - D_1^t \leq R_1 \qquad \forall t \in T \qquad (1)$$

then,

$$RM_1^t = RM_1^{t-1} - D_1^t + Q_{1,j}^t \qquad \forall t \in T, j \in J \qquad (2)$$

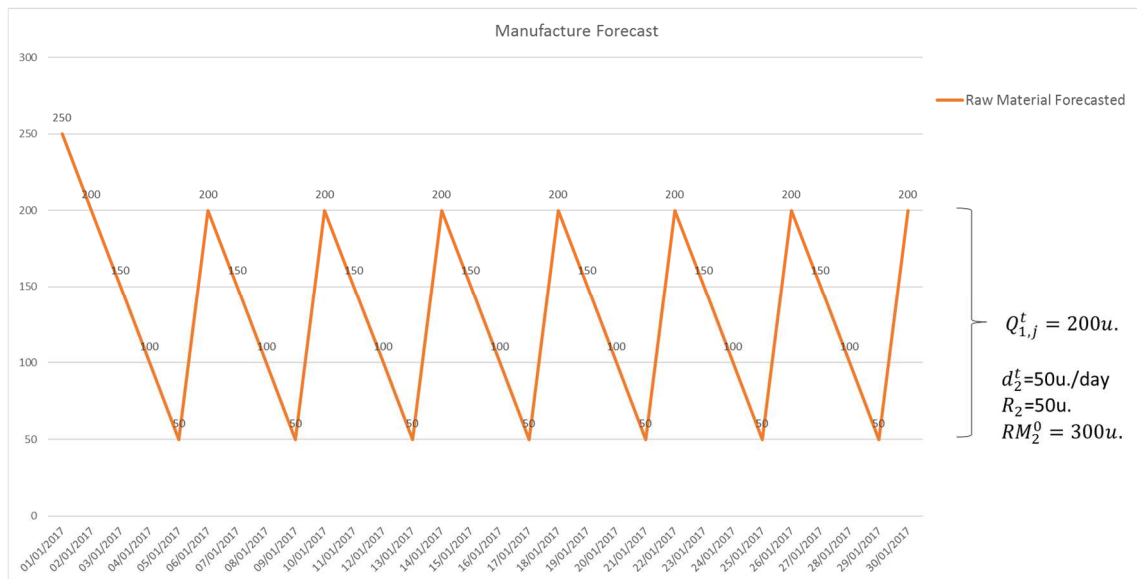then a purchase order $Q_{1,j}^t$ is sent to supplier.

Figure 3. Purchasing plan example from manufacture. Raw materials evolution.

Supplier

Once supplier receives a purchase order for a specific day, the supplier must deliver that purchase that day. It implies that if supplier cannot produce it the same day, it will advance this production.

Following the Just-In-Time policy to reduce the stock cost of finished goods, the production will be produced as late as possible. The next model moves all production as late as possible following the philosophy just-in-time:

Variables:

C_2 Maximum daily production capacity for supplier.

D_2^t Daily demand from supplier on day t from other costumers.

$Q_{1,j}^t$ Purchase lot size made by manufacture in day t to supplier.

$q_{2,j}^t$ Quantity produced at day t for a member of the supply chain.

$\Delta_{2,j}^t$ Accumulative q_1^t.

Objective function:

$$MIN\left\{\sum_{t=1}^{t=30}\left(q_{2,j}^t + \Delta_{2,j}^{t-1}\right)\right\} \qquad \forall j \in J \tag{3}$$

Subject to:

$$\sum_{t=1}^{t=30} q_{2,j}^t = Q_{1,j}^t \qquad \forall t \in T, j \in J \tag{4}$$

$$C_2 - d^{o t}{}_2 - q_{2,j}^t \geq 0 \qquad \forall t \in T, j \in J \tag{5}$$

$$\Delta_{2,j}^{t-1} = \Delta_{2,j}^t - q_{2,j}^t \qquad \forall t \in T, j \in J \tag{6}$$

At the end, the total month demand of supplier will be the sum of all daily demand of other costumers plus quantity daily produced for a member of the supply chain:

$$\sum_{t=1}^{t=30} D_2^t = \sum_{t=1}^{t=30} d_2^t + \sum_{j \in J}\sum_{t=1}^{t=30} q_{2,j}^t \tag{7}$$

Likewise manufacture, when raw materials stock reach less than its order point then a purchase order is sent to sub-supplier.

If

$$RM_2^{t-1} - D_2^t \leq R_2 \qquad \forall t \in T \qquad\qquad (8)$$

then,

$$RM_2^t = RM_2^{t-1} - D_2^t + Q_{2,j}^t \qquad \forall t \in T, j \in J \qquad (9)$$

t day is expected to receive materials from a purchase order from sub-supplier.
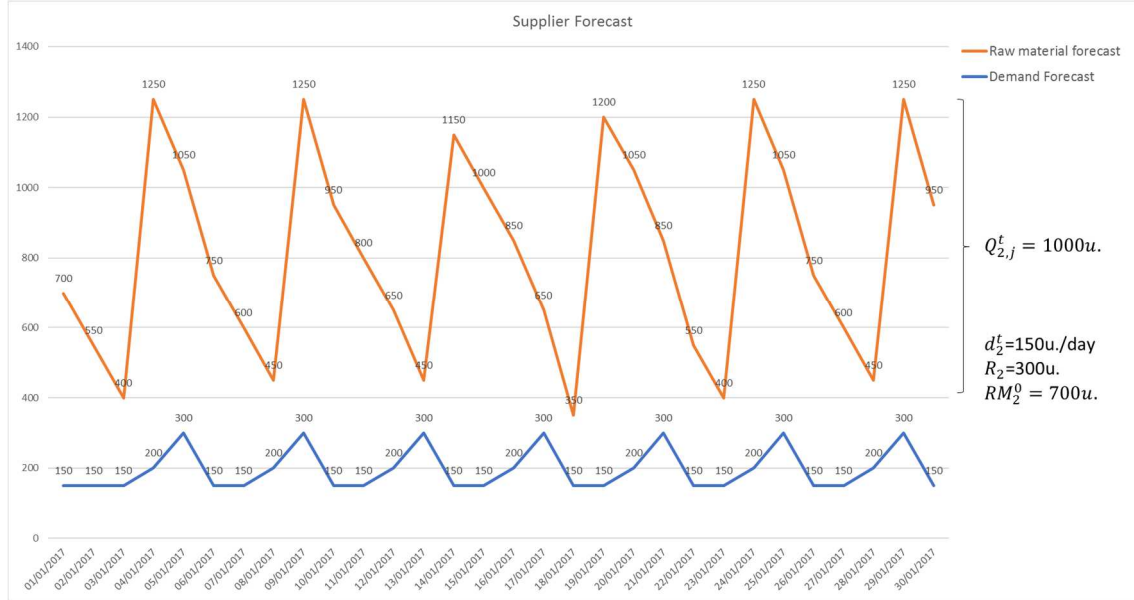
Figure 4. Purchasing plan example from supplier. Raw materials and demand evolution.

Sub-supplier

Likewise manufacture, when supplier receives a purchase order for a specific day, the supplier must deliver that purchase that day. The model used is the same as the one used before but changing variables.

Variables:

C_3 Maximum daily production capacity for sub-supplier.

D_3^t Daily demand of sub-supplier on day t from other costumers.

$Q_{2,j}^t$ Purchase lot size made by supplier in day t to sub-supplier.

$q_{3,j}^t$ Quantity produced at day t for a member of the supply chain.

$\Delta_{3,j}^t$ Accumulative q_3^t.

Objective function:

$$MIN\left\{\sum_{t=1}^{t=30} \left(q_{3,j}^t + \Delta_{3,j}^{t-1}\right)\right\} \qquad \forall j \in J \qquad (10)$$

Subject to:

$$\sum_{t=1}^{t=30} q_{3,j}^t = Q_{2,j}^t \qquad \forall t \in T, j \in J \tag{11}$$

$$C_3 - d_3^t - q_{3,j}^t \geq 0 \qquad \forall t \in T, j \in J \tag{12}$$

$$\Delta_{3,j}^{t-1} = \Delta_{3,j}^t - q_{3,j}^t \qquad \forall t \in T, j \in J \tag{13}$$

At the end, the total month demand of sub-supplier will be the sum of all daily demand of other costumers plus quantity daily produced for a member of the supply chain:

$$\sum_{t=1}^{t=30} D_3^t = \sum_{t=1}^{t=30} d_3^t + \sum_{j \in J} \sum_{t=1}^{t=30} q_{3,j}^t \tag{14}$$

Likewise, supplier and manufacture, when raw materials stock reach less than its order point then a purchase order is sent to another supplier that is not considered in that supply chain. In that point, it is assumed that all purchase orders made by sub-supplier will arrive at the proper time without any problem, because next level is not included in this model.

If

$$RM_3^{t-1} - D_3^t \leq R_3 \qquad \forall t \in T \tag{15}$$

then,

$$RM_3^t = RM_3^{t-1} - D_3^t + Q_{3,j}^t \qquad \forall t \in T, j \in J \tag{16}$$

t day is expected to receive materials from a purchase order from another supplier out from this supply chain.
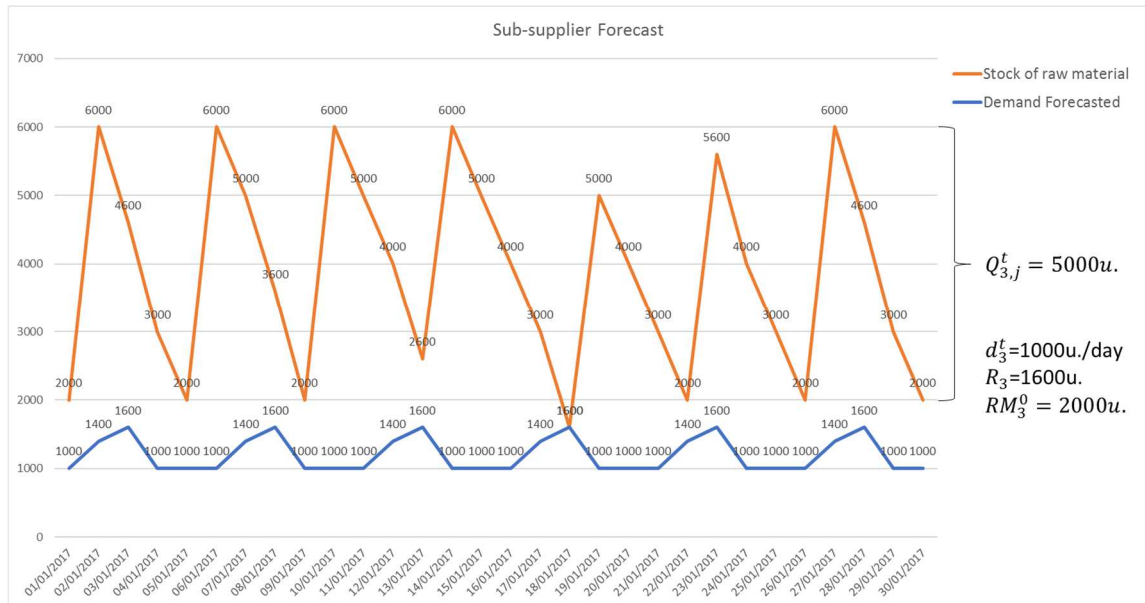

Figure 5. Purchasing plan example from a sub-supplier. Raw materials and demand evolution.

At the end of applying these methods what we will get is three things:

1st: The number of purchase orders that each member of supply chain will receive.

2nd: The number of purchase orders that each member of supply chain will send.

3rd: The production planning day for each member of supply chain.

Once purchasing forecasting is finished for every step of supply chain then there is a need for evaluate supplier and sub-supplier. Usually a supplier is evaluated by historical data, which is normally the most adjusted and the most reliable information, this information is just useful generally for selecting a supplier but not to evaluate it in a concrete moment. A supplier can be usually the best one and, at the same time, not be able to deliver a purchase for some reason, maybe because it has a peak demand that is unexpected or maybe because it has a lot of demand this month.

So, if a supplier is not evaluated by its historical data, how a supplier can be evaluated? One solution presented on this thesis is to test the supplier by introducing random normal variables with a mean equal to the forecasted demand of supplier. It is known that demand is usually not constant during a month, so it implies variability that can be simulated by these random normal variables. After simulating these data on the excel the manager will be able to see how these variabilities can affect into the system using KPIs and graphics.

4.2.6. Simulation method

The demand for a month can be determined for companies through many statistic or mathematical model. However, even though this demand can be founded with quite precision, it normally will not remain constant during the whole month. So instead of using a stable demand for the whole month, some random variables are added to forecasted demand to simulate a real case.

The kind of random variables used on this project follows normal distribution $X \sim N(\mu, \sigma^2)$, where priori mean is the forecasted demand:

$$\sum_{i=1}^{i=3} \mu_{priori_i} = \sum_{i=1}^{i=3} d_i \qquad (17)$$

Excel generates thirty variables with a mean μ_{priori_i} and variability σ for every day of the month. Variability will depend on how strong the simulation wants to be done. A small number of variability will involve a stable demand without much variation during the month and the ultimate results will not change too much from the forecasted situation. If instead of a small number an enormous number is putted as variability, then it will imply a lot of demand variation during the month and the whole supply chain will suffer in order to don't fail on delivery time of its customers.

Normal distribution	
μposteriori	49,93
σposteriori	9,11

Table 3. Posteriori mean and posteriori variation example

Once excel has calculated the random variables and has presented into its sheet, then the posteriori mean and variability are shown in dashboard to show to manager how biased are these variables from the initial ones.

So now the real demand from other customers of the whole month for each element of the supply chain will be:

Manufacture:

$$\sum_{t=1}^{t=30} RD_1^t = \sum_{t=1}^{t=30} D_1^t + (\chi_1^t - \mu_{priori_1}) \qquad (18)$$

Supplier:

$$\sum_{t=1}^{t=30} RD_2^t = \sum_{t=1}^{t=30} D_2^t + (\chi_2^t - \mu_{priori_2}) \qquad (19)$$

Sub-supplier:

$$\sum_{t=1}^{t=30} RD_3^t = \sum_{t=1}^{t=30} D_3^t + (\chi_3^t - \mu_{priori_3}) \qquad (20)$$

Formulas 18, 19 and 20 can be summarized as:

$$\sum_{i=1}^{i=3} \sum_{t=1}^{t=30} RD_i^t = \sum_{i=1}^{i=3} \sum_{t=1}^{t=30} D_i^t + (\chi_i^t - \mu_{priori_i}) \qquad (21)$$

Sub-supplier

First of all, what should be produced on day 0 is expected to be 0, so:

$$W_3^0 = 0 \qquad (22)$$

what it should be produced next days t are calculated by next formula:

$$W_3^t = RD_3^t + W_3^{t-1} - P_3^{t-1} \qquad \forall t \in T \qquad (23)$$

As can be seen not only considers the real demand of day t, it also considers what should be produced the days before. So, if for example what should be produced yesterday was not produced partially, then the remaining production would be produced next day first.

The raw material behaviour is conditioned by the raw material of the day before and the production made on the actual day. As it was told before, all purchases made by sub-supplier will be considered that there will be delivered on time, so each $Q_{3,j}^t$ will be added at RM_3^t at the forecasted delivery day.

$$RM_3^t = RM_3^{t-1} - P_3^t + Q_{3,j}^t \qquad \forall t \in T, j \in J \qquad (24)$$

A stock level security is also added into this system. Usually all manufactures that produce or sell products have a finished good stock just in case an unexpected reach of demand appears and made impossible the product deliver. An initial value for FG_i^0 is written in the dashboard at initial data, then finished goods stock is calculated with next formula:

$$FG_3^t = FG_3^{t-1} + P_3^t - RD_3^t \qquad \forall t \in T \tag{25}$$

The real production of the sub-supplier will be constrained by its daily capacity production C_i, the raw materials stock level RM_i^t and what should be produced W_i^t on that specific day. So, the real production will be the minimum value of each of these values.

$$P_3^t = MIN(C_3, RM_3^t, W_3^t) \qquad \forall t \in T \tag{26}$$

Not everything produced by P_i^t belongs to production of the supply chain, partially it is for other customer and partially is for the supply chain. Therefore, a new variable $\Delta\delta_{i,j}^t$ is needed for distinguish it, and it accomplish that:

$$\Delta\delta_{3,j}^t = P_3^t - RD_3^t + \Delta\delta_{3,j}^{t-1} \qquad \forall t \in T, j \in J \tag{27}$$

When $\Delta\delta_{3,j}^t$ reaches the value of the purchase order $Q_{2,j}$ then is sent to the supplier, this means that maybe this order is sent the planned day or later.

$$\sum_{t=1}^{t=30} Q_{2,j}^t = \sum_{t=1}^{t=30} \Delta\delta_3^t, j \qquad \forall j \in J \tag{28}$$

Depending on the final delivery date $Q_{i,j}^t$ can be different from the one forecasted, a new value $\tilde{Q}_{2,j}^t$ is used to express it.

The value of FG_i^t variates when the purchase order $\tilde{Q}_{2,j}^t$ is sent to the supplier:

$$FG_3^t = FG_3^{t-1} + P_3^{t-1} - RD_3^t - \tilde{Q}_{2,j}^t \qquad \forall t \in T, j \in J \tag{29}$$

Sub-supplier Real

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Stock of raw material	2000	6055	4597	3182	2295	6222	5234	3693	2093	6081	5191	4157	2620	6099	5305	4282	3420	1850	5250	4181	3208	2253	5871	4271	3096	2227	6314	4862	3262	2351
Real production	945	1458	1415	887	1073	988	1541	1600	1012	890	1034	1537	1521	794	1023	862	1570	1600	1069	973	955	1382	1600	1175	869	913	1452	1600	911	1143
Outcome Demand	945	1058	815	887	1073	988	1141	1004	1008	890	1034	1137	921	794	1023	862	1170	1116	953	973	955	982	1096	1079	869	913	1052	1044	867	1143
Stock level of Finished Goods	100	500	1100	100	100	100	500	1096	1100	100	100	500	1100	100	100	500	984	1100	100	100	500	1004	1100	100	100	500	1056	1100	100	

Legend:
- Stock of raw material — RD_3^t
- Real production — P_3^t
- Outcome Demand — d_3
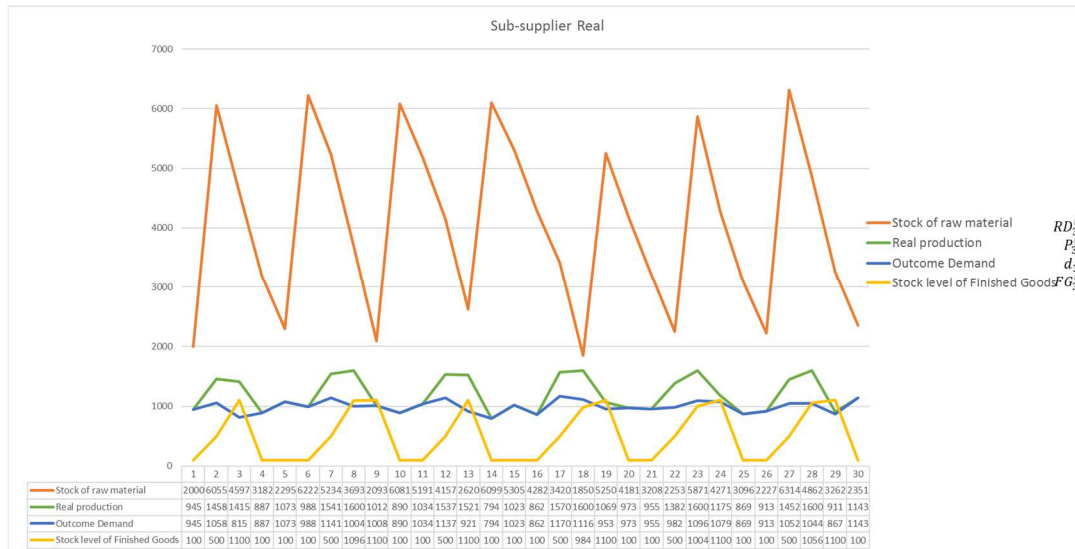- Stock level of Finished Goods — FG_3^t

Figure 6. Example of simulation situation in a sub-supplier

Supplier

All formulas written in the sub-supplier section are repeated for supplier changing its values and initial data in this section:

$$W_2^0 = 0 \qquad (30)$$

Just like sub-supplier, what it should be produced on day t is expressed like:

$$W_2^t = RD_2^t + W_2^{t-1} - P_2^{t-1} \qquad \forall t \in T \qquad (31)$$

The raw material behaviour is expressed like:

$$RM_2^t = RM_2^{t-1} - P_2^t + \tilde{Q}_{2,j}^t \qquad \forall t \in T, j \in J \qquad (32)$$

An initial value for FG_i^0 is written in the dashboard for supplier at the beginning, then the finished good stock is calculated with next formula:

$$FG_2^t = FG_2^{t-1} + P_2^t - RD_2^t \qquad \forall t \in T \qquad (33)$$

The real production of the supplier will be constrained by its daily capacity production C_i, the raw materials stock level RM_i^t and what should be produced W_i^t on that specific day. So, the real production will be the minimum value of each of these values.

$$P_2^t = MIN(C_2, RM_2^t, W_2^t) \qquad \forall t \in T \qquad (34)$$

The variable $\Delta\delta_i^t$ for distinguee outcome demand and supply chain demand is:

$$\Delta\delta_{2,j}^t = P_2^t - RD_2^t + \Delta\delta_{2,j}^{t-1} \qquad \forall t \in T, j \in J \qquad (35)$$

When $\Delta\delta_2^t$ reaches the value of the purchase order $Q_{1,j}$ then is sent to the manufacture:

$$\sum_{t=1}^{t=30} \tilde{Q}_{1,j}^t = \sum_{t=1}^{t=30} \Delta\delta_{2,j}^t \qquad \forall j \in J \qquad (36)$$

The value of FG_i^t variates when the purchase order $\tilde{Q}_{1,j}^t$ is sent to the manufacture:

$$FG_2^t = FG_2^{t-1} + P_2^{t-1} - RD_2^t - \tilde{Q}_{1,j}^t \qquad \forall t \in T, j \in J \qquad (37)$$
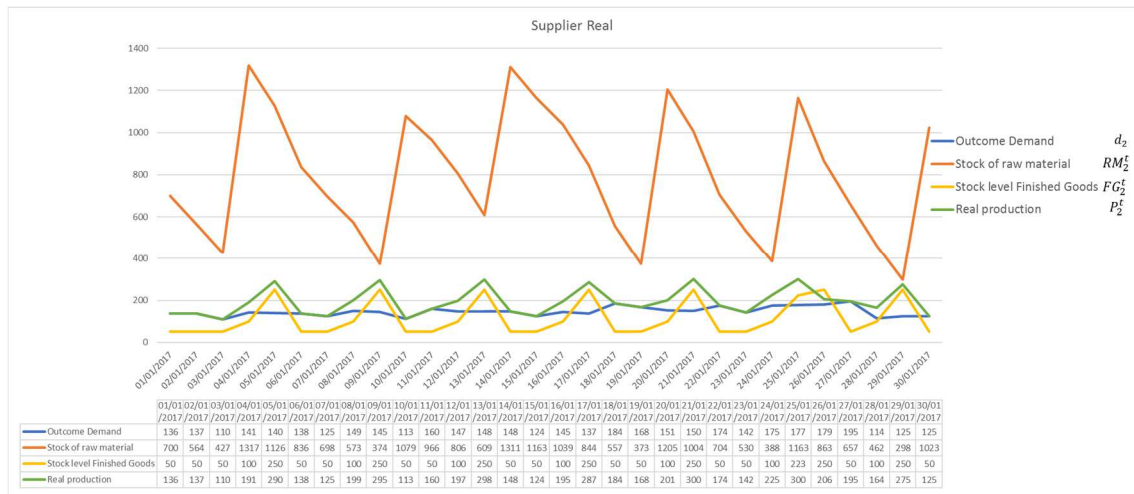

	01/01/2017	02/01/2017	03/01/2017	04/01/2017	05/01/2017	06/01/2017	07/01/2017	08/01/2017	09/01/2017	10/01/2017	11/01/2017	12/01/2017	13/01/2017	14/01/2017	15/01/2017	16/01/2017	17/01/2017	18/01/2017	19/01/2017	20/01/2017	21/01/2017	22/01/2017	23/01/2017	24/01/2017	25/01/2017	26/01/2017	27/01/2017	28/01/2017	29/01/2017	30/01/2017
Outcome Demand	136	137	110	141	140	138	125	149	145	113	160	147	148	148	124	145	137	184	168	151	150	174	142	175	177	179	195	114	125	125
Stock of raw material	700	564	427	1317	1126	836	698	573	374	1079	966	806	609	1311	1163	1039	844	557	373	1205	1004	704	530	388	1163	863	657	462	298	1023
Stock level Finished Goods	50	50	50	100	250	50	50	100	250	50	50	100	250	50	50	100	250	50	50	100	250	50	50	100	223	250	50	100	250	50
Real production	136	137	110	191	290	138	125	199	295	113	160	197	298	148	124	195	287	184	168	201	300	174	142	225	300	206	195	164	275	125

Figure 7. Example of simulation situation from a supplier.

Manufacture

Starting by:

$$W_1^0 = 0 \tag{38}$$

What it should be produced on day t is expressed like:

$$W_1^t = RD_1^t + W_1^{t-1} - P_1^{t-1} \qquad \forall t \in T \tag{39}$$

The raw material behaviour is expressed like:

$$RM_1^t = RM_1^{t-1} - P_1^t + \tilde{Q}_{1,j}^t \qquad \forall t \in T, j \in J \tag{40}$$

An initial value for FG_i^0 is written in the dashboard for manufacture at the beginning. If the value FG_1^t reach a negative number will mean that there is deferred demand and that the final product is not delivered at the agreed delivery date. So FG_1^t is a good indicator for manufacture if the whole supply chain is working properly or not, because it will affect directly to final customer:

$$FG_1^t = FG_1^{t-1} + P_1^t - RD_1^t \qquad \forall t \in T \tag{41}$$

The real production of the supplier will be constrained by its daily capacity production C_i, the raw materials stock level RM_i^t and what should be produced W_i^t on that specific day. So, the real production will be the minimum value of each of these values.

$$P_1^t = MIN(C_1, RM_1^t, W_1^t) \qquad \forall t \in T \tag{42}$$

In manufacture section, all demand is for final customer, so there is no need to use variable $\Delta\delta\,_3^t$.
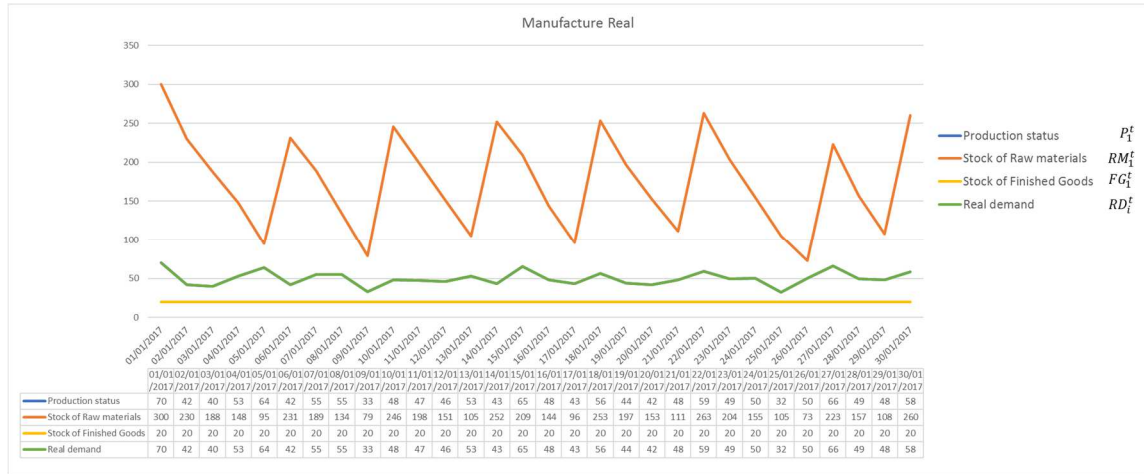

Figure 8. Example of simulation situation from a manufacture

4.3. Evaluating supply chain using KPI's

The use of Key Performance Indicators must help to a manager to see status of a supplier. The KPI's considered in that thesis are: saturation, capacity available, stock cost, reliability, average delivery time, maximum delivery time, minimum delivery time.

·Average saturation of production

$$Average\ saturation\ of\ production = \frac{Capacity\ available}{Total\ capacity} \qquad (43)$$

Percentage of saturation of a supplier shows how busy is a supplier, if a supplier is completely saturated it won't be able to satisfy any purchase order.

·Capacity available per day

$$Capacity\ available\ per\ day = Total\ daily\ capacity - Demand\ from\ outside \qquad (44)$$

It means available production capacity that a supplier has one day. This indicator must be equal or higher than manufacture's demand, if it is not so, the manufacture won't be able to deliver time its product to the customer.

·Total stock cost

$$Stock\ cost = Stock\ possession + Deferring\ demand + Launch\ of\ each\ purchase\ order \\ + Material\ purchase \qquad (45)$$

It adds stock possession, deferring demand, material cost and cost of launching a purchase order. In this project, total cost is not the main goal, but it can be a valuable data for a manager if it has many other indicators that are more or less equal.

·Reliability

$$\frac{Number\ of\ purchases\ delivered\ on\ time}{Number\ of\ purchases\ delivered} \qquad (46)$$

This is maybe the most important KPI of all, reliability means that a purchase ordered by manufacture has been delivered at the promised time or before. It is important to remember that one of the main goals of the project is to ensure the deliver on time to the costumer. If a purchase is delivered one or more days after the promised day it will be considered failed.

·Average delivery time

It indicates how long is the average of all the purchases made in one month to a supplier. The smaller is the average of delivery time, the better will be considered a supplier.

·Maximum delivery time

Among all delivers of the month, it indicates the biggest one.

·Minimum delivery time

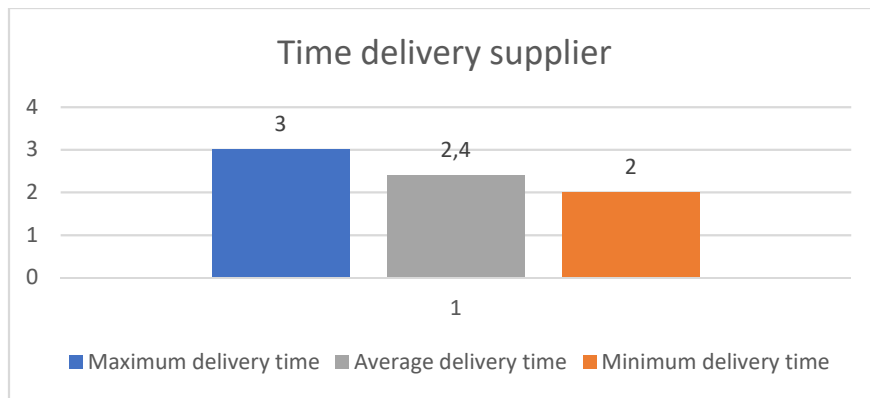Among all delivers of the month, it indicates the smallest one.

Figure 9. Example of graphic of delivery time

To get easier for a manager to interpret the information obtained by the program, excel generate a graphic for each element of the supply chain in forecasting or simulation situation:

1. Common forecasted purchase of a manufacture, a supplier and its sub-supplier. It comes accompanied by one graphic with four temporary lines: stock of raw materials, demand forecast, finished goods forecast and produced forecast.
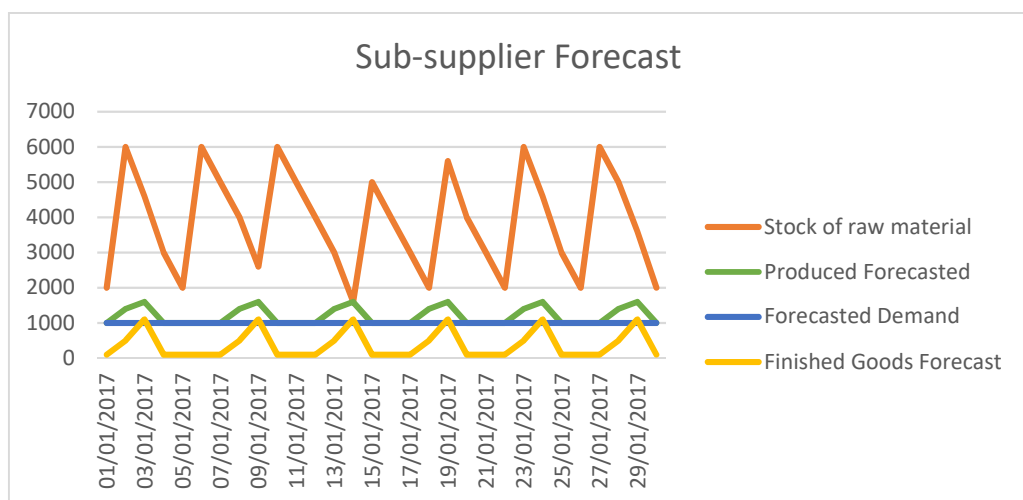

Figure 10. Example of graphic of sub-supplier forecast

2. *A simulation of a real case* applying the purchase policy. In this part, someone can notice the difference between what is forecasted and the result of applying what was forecasted. It also comes accompanied by a graphic with same lines as the graphic before mentioned.
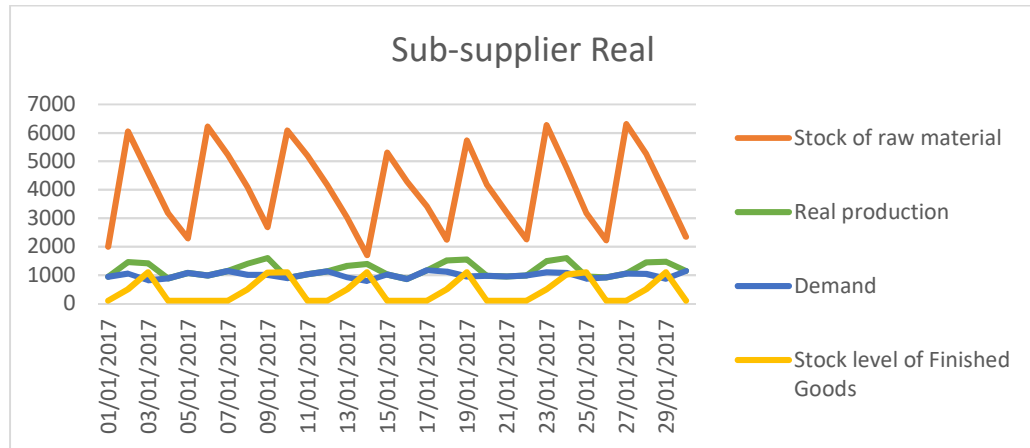

Figure 11. Example of graphic of sub-supplier simulation case

3. The KPIs before mentioned for manufacture, supplier and sub-supplier.

Forecasted Indicators		
Total number of PO recieved	6	purchases
Total number of purchase sent	6	purchases
Unit purchase number received	30000	units
Average delivery time	1,66666667	days
Average saturation	75	%
Available capacity per day	400	units/day
Available capacity per month	12000	units/month
Total cost of ownership	79800	DKK
Total cost of deferring demand	0	DKK
Total Cost	79800	DKK
Maximum delivery time	2	days
Minimum delivery time	2	days

Table 4. Example of indicator box in a forecasted case

Simulation Indicator		
Total number of purchase reiceved	6	purchases
Total number of purchase sent	6	purchases
Unit purchase number received	30000	units
Average delivery time	2,00	days
Average saturation	74,57	%
Available capacity per day	407	units/day
Available capacity per month	12208	units/month
Total cost of ownership	93191	DKK
Total cost of deferring demand	0	DKK
Total Cost	93191	DKK
Reliability Indicator	50,00	%
Maximum delivery time	3	days
Minimum delivery time	2	days
Maximum delivery time indicator	66,67	%
Minimum delivery time indicator	100,00	%

Table 5. Example of indicator box in a simulated case

Thanks to PFCR not only forecasting information can be shared but also real-time information. Through real time data demand, stock level and production status can variate and a manager need to know what will be the status of its manufacture always. So, introducing the real data instead of simulation on the excel, the manager can know how its manufacture is going to be affected in the future. It allows him to react accordingly and reconsider his options.

5. Use of results

The tool developed on that project allows a supply chain manager to gather all necessary information to take decisions consequently. All in dashboard is thought to show how is going to be affected the supply chain in future based on the decisions in the present.

All indicators in the dashboard are divided by three steps: the initial data, the forecasted KPI's and the real KPI'S.

- **Initial data:** This data is the information that needs to be added by a user by hand, excel needs it to create the purchase forecasting and the simulation.

- **Forecasted KPI's:** These KPI's are the ones that indicates what is going to happen if the demand remains stable during the whole month, it is good to have these KPI's in order to be able to compare it with the real KPI's.

- **Real KPI's:** These are the resulting KPI's after having used the simulation. These data will variate from the forecasted KPI's when the variation introduced in the model be high then the difference of KPI's will be high as well.

The main values that are considered most important in that project are reliability, delivery time, cost and saturation. All indicators are focused on evaluate the supplier/sub-supplier in order to evaluate the best one for a specific planning.

- **Reliability:** It's the percentage of a supplier to deliver the product at the correct delivery time without delays. This indicator shows how reliable is a supplier delivering raw materials. It's is a crucial factor because a delay in delivery implies a delay in the manufacture and, therefore, a certain delay in the final delivery of the consumer.

- **Delivery time:** It's the existing time is the time between sending an order and receiving it. This factor is closely related with reliability. A good reliability factor for a supplier is not useful if the delivery time is too high, so it means that reliability and delivery time must be balanced. In the dashboard delivery time is presented in three ways: maximum, minimum and average of all the purchases received that month.

- **Saturation:** Despite capacity is one of the main factors to produce faster than other competitors, the level of saturation shows how many purchase orders a supplier have to manage before yours. A clear example of that situation would be for example a supplier that has a huge capacity of production but at the same time is working at its full capacity because it has many purchase orders to deliver. Despite a supplier can have a lot of production capacity, if it has many other customer or demand to satisfy it will be easier to collapse and not be able to deliver your purchase order at the right time.

- **Cost:** Cost factor is maybe the less important one to deliver the product, but all companies interested in reducing purchasing costs. So, it is important to have it in mind anyway. Nevertheless, is also important to know how much is going to cost the purchase order compared with standard price of the product, if the price is too high maybe is not worthwhile to accept it. It is also interesting to have this indicator into account if other suppliers have more or less the same values on the indicators above mentioned.

The evolution of raw materials, production, demand and finished goods presented in graphics tell in a fast way if the data introduced in the initial data will be able to satisfy the customer. It's a useful way to present the information fast, easy and intuitively.

The tool can be used also as a monitor at real time. It would help to a manager to react in an unexpected change in some member of the supply chain. So, if instead of use the simulation part with random variables the real demand of the month is added, then the closed future can be predicted and controlled easily.

Figure 12. Image of sub-supplier panel control.

Figure 13. Image of the whole dashboard

6. Discussion

Not all products delivered on time pass quality control. As reliability or delivery time, quality is an important item that point which supplier are most reliable producing raw materials, if the raw material doesn't have enough quality implies that the purchase order must be repeated and the supply chain has lost a valuable time.

Despite quality should be also another KPI included in the model and it's also an important item to take it into account, in this project, it has not been included because it would increase the complexity of calculations. In future researches quality would be an interesting KPI to add into the model that would approach it to a more real situation.

7. Experiment

Hereinafter is going to do a little test to see how a supply chain react in two different scenarios. It will be interesting see how results and graphics in the dashboard change. In both cases internal capacities of supply chain and demand won't variate. What will change will be variation in random variables generated by excel in the simulation step. It is going to create two different scenarios in which one will be friendly for the supply chain and the other not:

- Stable or friendly: The priori variation regarding its mean will be a 5%.

	Manufacture	Supplier	Sub-supplier
Demand priori	50	150	1000
σ priori	2,5	7,5	50

Table 6. Priori mean and variance from friendly scenario

- Instable or unfriendly: The priori variation regarding its mean will be 20%.

	Manufacture	Supplier	Sub-supplier
Demand priori	50	150	1000
σ priori	10	30	200

Table 7. Priori mean and variance from unfriendly scenario

Initial data for both cases:

First of all, initial data needs to be add by hand in the excel. The data is the same in both scenarios. The only thing that change is the simulation demand data. In table 8 and 9, it can be seen the initial data introduced into manufacture, supplier and sub-supplier:

Manufacture			Supplier		
Initial data			Initial data		
Production capacity	200	units/day	Production capacity	300	units/day
Order point	50	units	Order point	300	units
Purchase order lot	200	units/lot	Purchase order lot	1000	units/lot
Initial stock of raw material	300	units	Initial stock of raw material	700	units
Security stock	20	units	Security stock	50	units
Daily demand	50	units/day	Daily demand	150	units/day
Launch purchase order cost	700	DKK	Launch purchase order cost	700	DKK
Cost of ownership	7	DKK	Cost of ownership	7	DKK
Cost of deferring demand	21	DKK	Cost of deferring demand	21	DKK
Purchase unit cost	2	DKK	Purchase unit cost	2	DKK

Table 8. Initial data introduced in manufacture and supplier

Sub-supplier		
Initial data		
Production capacity	1600	units/day
Order point	1600	units
Purchase order lot	5000	units/lot
Initial stock of raw material	2000	units
Security stock	100	units
Launch purchase order cost	700	DKK
Daily demand	1000	units/day
Cost of ownership	7	DKK
Cost of deferring demand	21	DKK
Purchase unit cost	2	DKK

Table 9. Initial data introduced in sub-supplier

Despite mean and variance has been introduced in a fix number in order to generate random variables, these numbers variate with final results, as it can see in next figures:

Stable:

Normal distribution		Normal distribution		Normal distribution	
μposteriori	1004,40	μposteriori	148,17	μposteriori	49,37
σposteriori	53,80	σposteriori	6,87	σposteriori	2,08

Table 10. Posteriori mean and variance from friendly scenario.

Instable:

Normal distribution		Normal distribution		Normal distribution	
μposteriori	962,07	μposteriori	149,83	μposteriori	50,47
σposteriori	194,76	σposteriori	30,47	σposteriori	9,44

Table 11. Posteriori mean and variance from unfriendly scenario

In figure 14 on next page it can see how purchase order are distributed and planned for the whole month for a constant demand. The planning starts by manufacture, and then it is followed by supplier and sub-supplier as it has been explained in chapter 3 (methodology) of this project.

It can see that there is no variation on finished good line in figure 14, so it means that if demand would remain constant there would not have any delay in delivering a purchase orders.

Figure 14. Resulting graphics before simulation

In figure 15 it can see how a 5% variance respect its demand (or stable scenario) affects to supply chain. Supply chain can tolerate a small variance of demand without problems in that case.
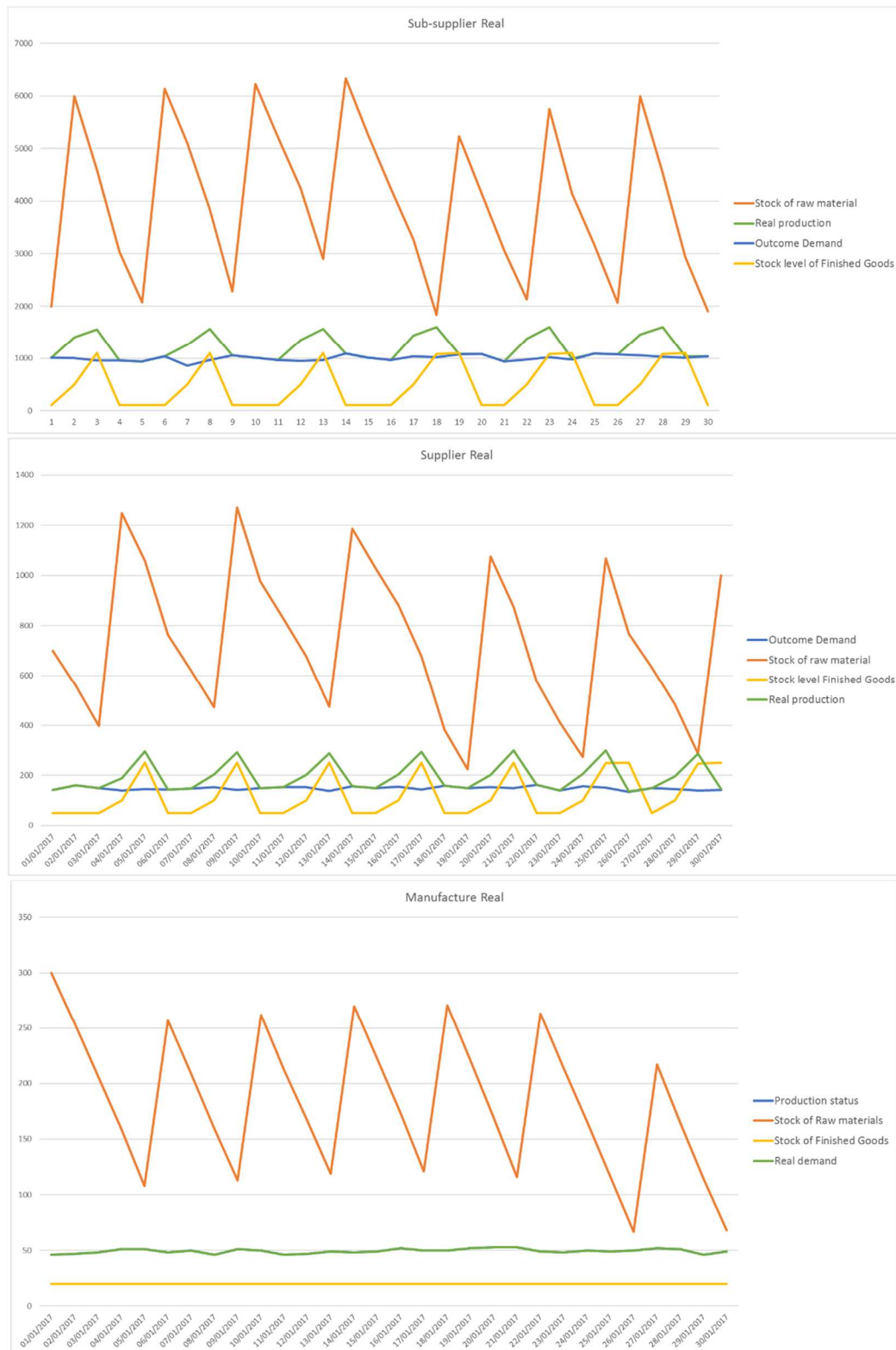

Figure 12. Resulting graphics after simulation from stable scenario

In figure 16 are graphics of unstable simulation with a 20% variance respect its mean. Like it can observe in manufacture, in some days of month it starts to have problems with raw materials stock. These problem with raw materials affect directly to finished goods level, which is not remain constant like the in other the scenario. Anyway, in that case final product can be delivered on time because finished goods level never reaches negative number, but maybe with another variable with the same priori mean and variance, it could be some problems in delivering on time.
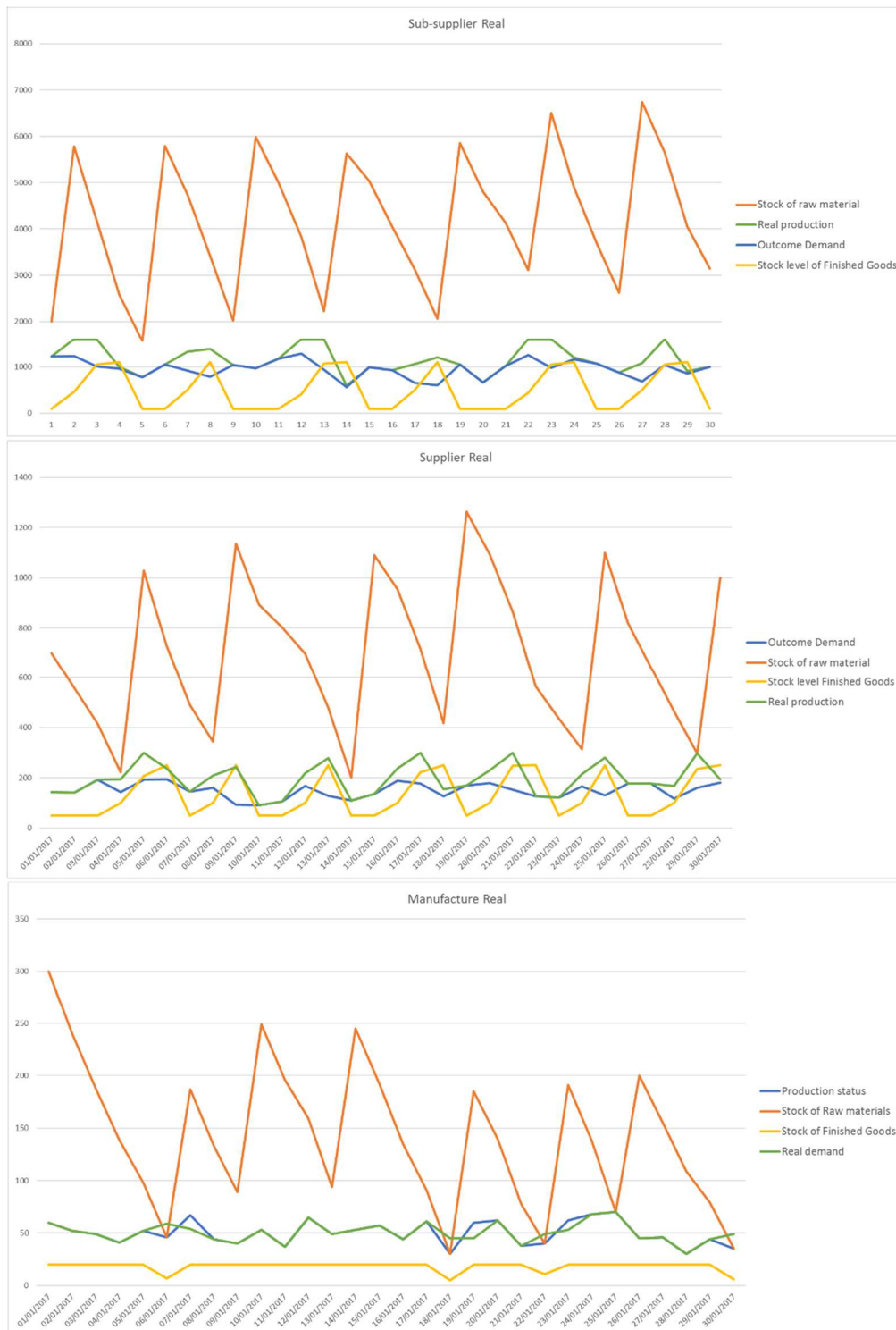
Figure 16. Resulting graphics after simulation from instable scenario

Manufacture			Supplier			Sub-supplier		
Simulation Indicator			Simulation Indicator			Simulation Indicator		
Total number of purchase send	7	purchases	Total number of PO sent subs	6	purchases	Total number of purchase reiceved	6	purchases
Unit purchase number send	1400	units	Total number of PO received subs	6	purchases	Total number of purchase sent	6	purchases
Average saturation	24,68	%	Unit purchase number received	6000	units	Unit purchase number received	30000	units
Available capacity per day	151	units/day	Average delivery time(*)	2,16666667	days	Average delivery time(*)	2,50	days
Available capacity per month	4519	units/month	Average saturation	64,94	%	Average saturation	75,28	%
Total cost of ownership	4200	DKK	Available capacity per day	105	units/day	Available capacity per day	396	units/day
Total cost of deferring demand	0	DKK	Available capacity per month	3155	units/month	Available capacity per month	11868	units/month
Total cost of purchases	7700	DKK	Total cost of ownership	25522	DKK	Total cost of ownership	100373	DKK
Total Cost	11900	DKK	Total cost of deferring demand	0	DKK	Total cost of deferring demand	0	DKK
			Total cost of purchases	16200	DKK	Total cost of purchases	64200	DKK
			Total Cost	41722	DKK	Total Cost	164573	DKK
			Reliability Indicator(*)	71,4285714	%	Reliability Indicator(*)	50,00	%
			Número total de PO recibidas manu	7	purchases	Maximum delivery time(*)	3	days
			Número total de PO enviadas manu	6	purchases	Minimum delivery time(*)	2	days
			Total number of units recibidas	1400	units			
			Maximum delivery time(*)	3	days			
			Minimum delivery time(*)	2	days			

Table 12. Resulting KPI's from friendly scenario.

Manufacture			Supplier			Sub-supplier		
Simulation Indicator			Simulation Indicator			Simulation Indicator		
Total number of purchase send	7	purchases	Total number of PO sent subs	6	purchases	Total number of purchase reiceved	6	purchases
Unit purchase number send	1400	units	Total number of PO received subs	6	purchases	Total number of purchase sent	6	purchases
Average saturation	25,00	%	Unit purchase number received	6000	units	Unit purchase number received	30000	units
Available capacity per day	150	units/day	Average delivery time(*)	2,5	days	Average delivery time(*)	2,67	days
Available capacity per month	4500	units/month	Average saturation	65,50	%	Average saturation	72,63	%
Total cost of ownership	3843	DKK	Available capacity per day	104	units/day	Available capacity per day	438	units/day
Total cost of deferring demand	0	DKK	Available capacity per month	3105	units/month	Available capacity per month	13138	units/month
Total cost of purchases	7700	DKK	Total cost of ownership	27755	DKK	Total cost of ownership	105385	DKK
Total Cost	11543	DKK	Total cost of deferring demand	0	DKK	Total cost of deferring demand	0	DKK
			Total cost of purchases	16200	DKK	Total cost of purchases	64200	DKK
			Total Cost	43955	DKK	Total Cost	169585	DKK
			Reliability Indicator(*)	42,8571429	%	Reliability Indicator(*)	33,33	%
			Número total de PO recibidas manu	7	purchases	Maximum delivery time(*)	3	days
			Número total de PO enviadas manu	6	purchases	Minimum delivery time(*)	2	days
			Total number of units recibidas	1400	units			
			Maximum delivery time(*)	3	days			
			Minimum delivery time(*)	2	days			

Table 13. Resulting KPI's from unfriendly scenario.

As table 12 and 13 show, variation on demand greatly affects on supply chain and KPI's of each of its participants. When bigger is instability of demand, more all supply chain is delayed in its deliveries, it also gets a worse are the results in terms of reliability and average delivery time.

Saturation level is a KPI that, in that case it's not very relevant, because normal distribution of variables makes it constant in both scenarios.

A curious data is that cost indicator in manufacture is cheaper in instable scenario. It can be explained because, at some point of month the stock level of finished goods is reduced and, consequently, it reduces the cost of stock possession.

Finally, in both cases manufacture can produce its demand without problems, but an increase of variation in demand would affect negatively into the whole supply chain.

8. Conclusions

That project has developed a dashboard for a supply chain in order to help a supply chain manager to get a complete overview about the status of its chain. The reason to do a dashboard is to make decision making easier. The method used for developing it has been to create a common purchase planning for the whole chain using an order point policy. Then a simulation for a real case has been added into that dashboard.

Finally this dashboard has been tested with a little experiment that has shown the behaviour of the supply chain in two different scenarios of different demands.

To sum up it can be said that the dashboard that has been developed in that project is very limited and cannot be applied in many real circumstances.

First of all, transport is not taken it into account in delivery time, and it is normally one of the main factors that affects.

Another limitation is that it is considered one raw material to produce just one final product, when normally this relation is many to one or one to many. Usually in order to produce a unit of product it is necessary many different kinds of raw materials, which makes the problem bigger and more complex for a supply chain manager.

Demand is not something that should follow any kind of behaviour and it can be very random, which is something very common in a real case. This dashboard just considers an stable demand and doesn't tolerate very well large variation in a simulation case.

This dashboard has demonstrated be very demanding with every member of supply chain and a good tool to detect problems before they occur. It's is also very useful to evaluate every member in a quantitative way.

It has also demonstrated be very intuitive and easy to use for a user.

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10. Acknowledgments

I really would like to thank to professor Peter Jacobsen, who is my tutor and has been my guide during last months, to develop this project. He has helped me and has contributed to realize this project.

I would also like to thank Gema Sánchez to help me in checking and correcting some language mistakes in the report.