Group model building and quantitative modeling applied to a supply chain problem

by
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Table of contents

List of figures

List of tables

Acknowledgements

As always, thanks God for giving me this life full of so many marvelous gifts. I will keep doing my best to deserve it.

To my mother and my grandmother because there is never enough opportunity to thank them for everything.

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Dedication

To Maria

Abstract

The spare parts supply chain at heavy equipment distribution company presents two problems: high inventory and order instability. The goal of this thesis is to investigate their causes and inform on possible solutions. The research used group model building as a method to involve the stakeholders in the modeling process and to foster learning and commitment towards implementation of the policies defined. System dynamics simulations are used to understand the behavior of the model built with the group and to test hypotheses about the possible causes of the problems defined. The research concludes that the ordering policy from the company to the supplier, misperceptions of past sales, misperceptions of the inventory on hand, and lack of trust among key actors in the supply chain causes order instability, and leads to higher-than-desired inventory levels. The implications of the research are expressed in the policy recommendations of the project: (a) the sources of information about sales and inventory on hand used in the ordering process to the supplier must be corrected in order to avoid misperceptions at the decision making level, and (b) orders, sales and inventory information must be shared between key actors in the supply chain in order to increase transparency and build trust.

Introduction

Supply chain systems have concerned system dynamicists from the very inception of the field (Jay W Forrester, 1961). However, the challenges faced by organizations involved in the management of supply chains appear to be far from solved (Akkermans, 2005). One of those organizations is UMG. Established in Myanmar[1] in 1998, UMG distributes heavy machinery equipment (in special excavators) and provides the service and spare parts required by the machines. The company has seen permanent growth since its foundation, extending its operations to more than 13 branches all across the country.

The spare parts distributed by UMG involve a broad range of products, from small pieces of plastic rings to complex electronic and hydraulic devices. In order to distribute the products efficiently to its customers, UMG have established a spare parts supply chain: spare parts are imported from international suppliers, stored in inventory and delivered to the customers.

During the last years, managers at different levels, including the company's CEO, have perceived that, as the company grows, the management of its spare parts supply chain have became more difficult. This situation motivated the company's CEO to search for a method that could help to structure the problem, explain its causes and guide the search for solutions.

This thesis reports the process and outcomes of a three-month system dynamics project that involved the use of computer simulation and Group Model Building to discover the main problems of the spare parts supply chain at UMG and to shed light on possible solutions.

The order of the chapters resembles the chronological order in which the project was executed. First I introduce the company and present a description of group model building as the methodological approach, a justification of its use and I describe how the GMB project was planned.

The project was planned in three sessions: the first session was targeted to define the problem, the second session to build a causal structure that could generate the problematic behavior, and the third session to find possible policies for improvement. After the first and second session, a quantitative simulation model was built based on the model elicited with the group. Each model was analyzed in order to provide feedback to the participants on the behavior of the model and on the causes for its behavior.

[1] Also known as Burma

[2] Interestingly this situation, that served as an illustrating example in (Vennix, 1996), would occur

The project focused on two problematic behaviors: growing inventory and order instability. Across the sessions, I found that the main reason for instability was the ordering policy used by UMG to order spare parts to its suppliers. Furthermore, I found that in the structure elicited from the group there were two phenomena that could cause further order instability and lead to higher-than-desired inventory levels: (a) a misperception of the parts sales, and (b) a misperception of the inventory available. When both sources of information were used, the system presented instability in orders and inventory growth. The results from this analysis were presented to the group in the third and last session, when policies for improvement should be defined.

The discussion of the policies for improvement led not only to possible solutions to the misperceptions just mentioned, but also introduced new dynamics that showed the mistrust that exists between the central administration of UMG and its branches. Such unexpected event would be definitive in the definition of the policies to be implemented, where the issue of trust was central.

For each session, one chapter is devoted to present how the session was prepared and conducted, followed by a description of the simulation model built, the analysis of its behavior and the conclusions derived from the analysis.

After the description of the work done during the project, I discuss the use of GMB in the context of the project. How the people at UMG received the approach, what worked well and what did not work so well according to my criteria. I also present a list of learned lessons that emerged across the sessions.

Following the discussion, a chapter is devoted to the project conclusions. The closing chapter is a critical reflection about how I conducted the study, and what it meant for the quality of the model and its conclusions.

Chapter 1. UMG's spare parts supply chain

1.1 Introduction to UMG

UMG is a company established in Myanmar in 1998 as a distributor of heavy machinery equipment (mostly excavators, trucks and drilling machines). Along with the distribution of machines, the company provides the service and spare parts required for their maintenance and repair. Hence, the company's operations can be divided into three business lines:

- Heavy machinery distribution
- Provision of service to the installed
- Base and spare parts distribution

The company has seen a permanent growth trend since its foundation, as reflected by the fourfold increase in the company's installed base in the period 2007-2012 and more than twofold (53%) in the period 2010-2012 (Figure 1).

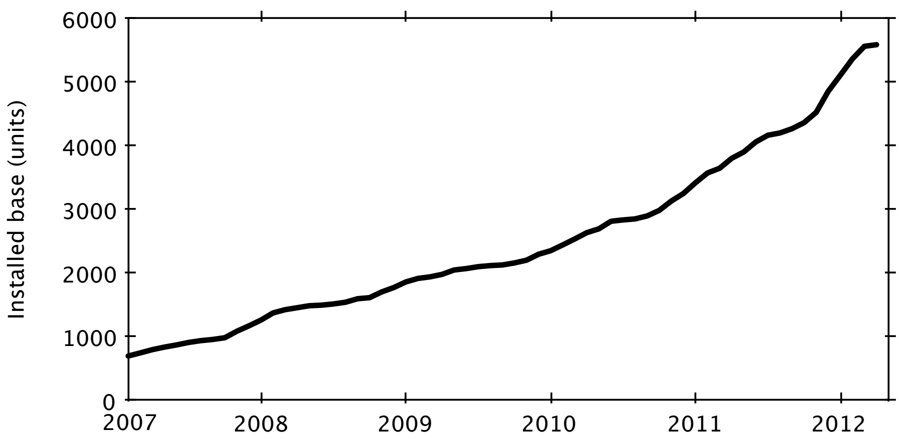

Figure 1. Evolution of UMG's installed base over time

1.2 UMG's spare parts distribution

The distribution of spare parts is critical to UMG's clients. An efficient and timely distribution leads to uninterrupted machine working time. Lack of spare parts when needed leads to machines out of service, a situation undesirable for UMG's customers. Furthermore, UMG is the exclusive supplier of genuine parts for several of the brands it distributes. Such exclusivity causes customers to depend strongly of the efficiency and effectiveness of UMG's distribution. At the moment the company distributes around 2500 different types of spare parts to more than 100 customers all across Myanmar. In order to fulfill the growing spare parts demand, UMG has established a distribution supply chain. Figure 2 depicts in circles the main actors involved in the supply chain. The arrows represent flows of spare parts, orders or information among the actors. The numbers between brackets represent the delays in months of each information flow. The actors are described as follows:

- The manufacturers of spare parts: UMG purchases the parts directly from about 12 manufacturers, all of them located in different countries across the southeast Asia region.
- UMG's main warehouse, also called Head Office (HO) where all overseas shipments are received and distributed to the branches.
- 12 branches around the country where the spare parts are received from the main warehouse and delivered to the customer.
- The customer itself, who often keeps certain levels of inventory of spare parts according to characteristics such as budget available and the size of their own installed base.

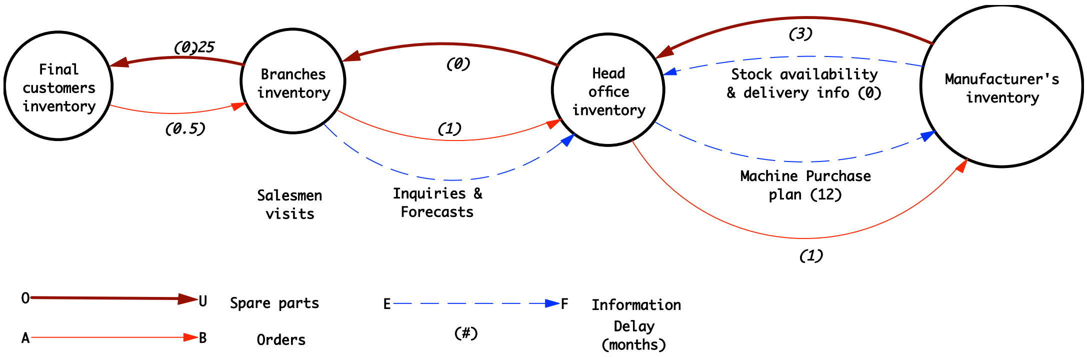

Figure 2. The main actors of the spare parts supply chain

Branches and HO keep inventory on hand for the spare parts with higher demand. For spare parts with less demand, or for higher-than-usual order quantities, customers must place a *custom order* in advance in order for UMG to import the spare parts from the manufacturer. In special cases, where a spare part is required with urgency, the customer places an *emergency order*. The process followed by the customer when placing each type of order is presented in the flow diagram of Figure 3. Each circle represents the start of the ordering process for each type of order. Rectangles represent an action and the diamonds represent decision points.

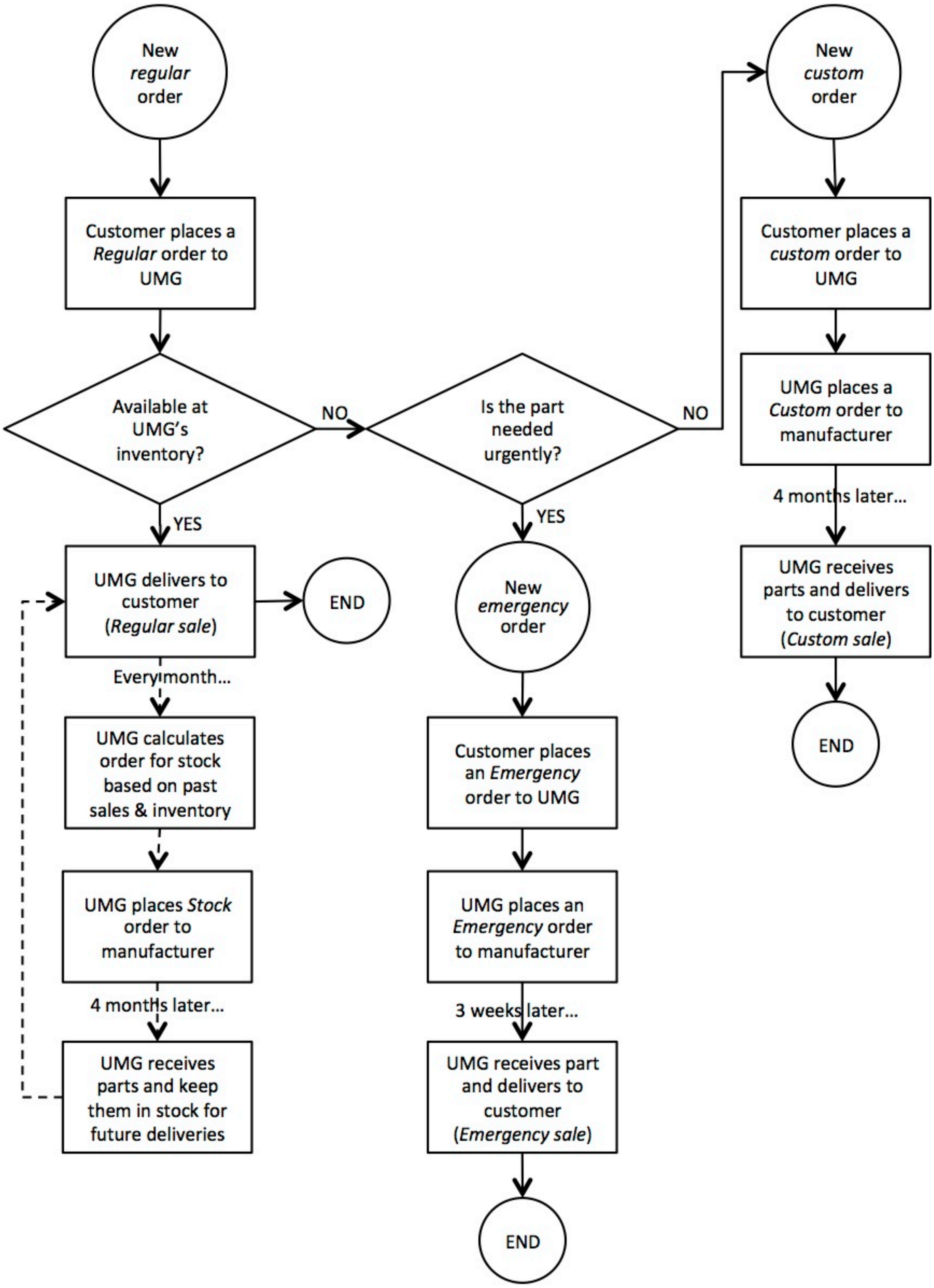

Figure 3. Process followed by orders at UMG

The process followed by each type of order is described below:

1. Regular orders: Are called regular because they are predictable in terms of the frequency in which the order is placed, and the quantity ordered. Because the order quantity lies between the regular sales estimates made by UMG, it is often available in stock; hence it is delivered by UMG from its inventory. Such delivery is called a *regular sale*. To fulfill its inventory and satisfy the frequent regular orders from customers, UMG places monthly orders to the

manufacturers. After a lead-time of 4 months, the parts arrive, replenishing the current stock.

2. Custom orders: Are called custom because are customized orders from particular customers. The order is customized because it usually exceeds the quantity available at UMG's inventory, making it impossible to deliver them as regular sales. Customers make custom orders to cover the usage of a spare part for several months (even a year). Custom orders are not delivered from UMG's inventory but are delivered directly from a shipping received from the manufacturer. By doing custom orders customers get lower costs due to volume discounts. Deliveries to customers from custom orders are called *custom sales.* The average lead-time for a custom order is 4 months.
3. Emergency order: Parts that are not in UMG's inventory, but are required urgently (usually because a machine cannot work unless the spare part is replaced) can be ordered through an emergency order. Such orders guarantee shorter lead-times by using faster mediums of transportation and special agreements with the manufacturer (although with extra costs). Delivery of parts aimed to fulfill an emergency order is also called an *emergency sale*. The average lead-time for emergency orders is 3 weeks.

1.3 A note on seasonality

Most operations at UMG are heavily influenced by weather seasonality. The *monsoon* bring along a season of heavy rain countrywide, starting in May and ending in October every year. During this season, not by chance called *rainy season*, most of the machines stop operations (an estimate of only 10% keep working). Hence, seasonality may appear as an important factor to be taken into account in the modeling effort.

Chapter 2. Methodological approach

The previous chapter leads to the question of what are the major concerns in the spare parts supply chain, in other words, to the question of the problem definition. To address such a question, it is necessary to review first how the problem was defined in the previous SD projects executed in the company, since those events affected the planning and execution of the current project.

2.1 Problem definition in the previous system dynamics efforts at UMG

One of the characteristics of the previous system dynamics projects executed in the company was the methodology followed to define the problem (Huertas, 2011). The CEO would perceive the problem symptoms and would state the problem in bold terms. The system dynamics consultants (the author included) would then collect numerical data related to the reference mode and call for a meeting where the main stakeholders involved would be present. In the meeting, the consultants would present the problem as stated by the CEO and then present the reference mode data. Such reference modes were assumed to represent "the problem" to be modeled. Once the problem was presented, discussions targeted at finding its causes and possible solutions would follow. From those discussions, further interviews and data collecting, the modeler would develop a simulation model, from which policy recommendations would arise.

At the beginning of the current project, an analysis of the approach to problem definition was made with the intention to evaluate how the approach could be improved and which actions should be avoided. The analysis resulted in two conclusions, presented below.

First, the problem definition used during the previous modeling efforts was based on the definition provided by the CEO only even if during the rest of the modeling process other stakeholders were going to be included. This practice had the implicit assumption that that the problem was objectively defined by the CEO and that its definition was shared among all participants. However, Vennix (1996) has warned against this assumption when it comes to organizational decision making: People do not have a single representation of reality. Every person builds her own mental model, selecting what is perceived from the environment as reality and what is memorized from situations as past facts. Even apparently simple and objective situations that are based on quantifiable facts, such as deciding if a level of inventory is too high or too low, can be subject to different perceptions and interpretations among people from different divisions in an organization[2].

In the paragraph above, it was concluded that the assumption that the problem definition was shared among all stakeholders was quite optimistic. In other words, there was a possibility that the problem, as stated by the CEO, was not interpreted in the same way by the others, or was not even interpreted as “the” problem.

Lack of a common interpretation among a group of what the problematic situation is could have affected negatively the outcome of previous modeling processes. Furthermore, Roberts (1978) has pointed out that implementation of recommendations from system dynamics models is more likely to occur when the problem targeted is recognized as a problem among the stakeholders. If the stakeholders do not recognize the situation under scrutiny as a problem, chances of a successful implementation of any model conclusion are reduced.

The second conclusion was related to the way the intervention to define the problem was conducted: In order to collect data for the reference modes and make the first “problem definition presentation” to the stakeholders, the CEO would initiate the project and provide public support to the modeler on the data collection process. Schein (1995) has warned how a “data collection” stage supported by the CEO in a company represents a non-negotiable intervention that can affect the people to whom it is done. Even if collecting data is seen as preceding the “actual” intervention, it can have unpredictable consequences in the whole process.

In the case of UMG, the reaction of the stakeholders to the data collection stage occurred at the moment the modeler presented the reference modes to the group. On one hand, most of the data shared by managers at UMG is presented in form of indicators, showing values for the current and immediately preceding year (i.e. see Figure 4). On the other hand, the reference modes presented spanned for several years in the past. Thus, the reference modes did not correspond to the time horizon of the data used regularly by the company’s managers. Furthermore, the graphs were not shared with the persons involved before the presentations. The result during the “problem definition” meeting was often surprise among the people directly related with the data, followed by reactions that could qualify as ‘defensive’: Direct questioning of the sources from where the data was extracted, even if the person asking was the same person who provided the data in first place, or taking immediately the word in order to explain the reasons for such historical data even if it was stressed that a more structured process would come later in the session to do so.

[2] Interestingly this situation, that served as an illustrating example in (Vennix, 1996), would occur soon in the thesis project.

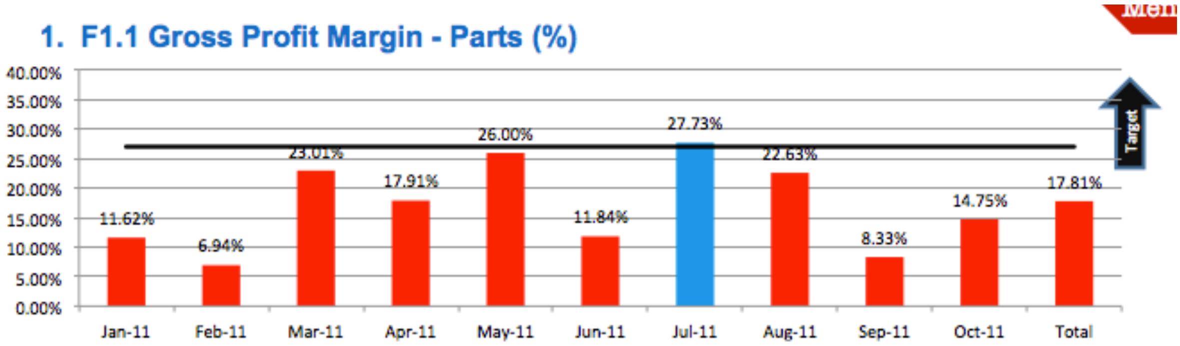

Figure 4. Typical presentation of data among managers at UMG

The causes for taking a defensive behavior in the setting of a presentation in which other managers and the CEO are present can be tracked to the embarrassment participants could have felt while being confronted with numerical data reflecting problematic situations: "Faced with an embarrassing situation people normally start a so-called face-saving operation" (Vennix, 1996).

This method of presenting reference modes to the group may have influenced the problem definition, by creating an atmosphere of defensiveness with the modeler, who was seen rather as an "auditor" who was trying to surface problems in unseen ways. By focusing on the face-saving operation, people were prevented to enter into a more constructive discussion of the problems being presented.

In summary, the method followed for the problem definition had two flaws: (a) there was a high chance that there was not a common understanding of the problem defined since the process did not include explicitly methods to achieve such a goal among all participants, and (b) it created an atmosphere of defensiveness that may have affected not only the problem definition stage but the whole remaining project.

Given such conditions, Group Model Building was evaluated as an alternative approach.

2.2 Group model building: method and practice

2.2.1 The GMB method

Group model building (GMB) is a methodological approach to system dynamics modeling in which a group of stakeholders related by a problematic situation participates actively in all the stages of the model construction (George P Richardson & Andersen, 1995; Vennix, 1996).

GMB provides guidelines to structure group sessions in which participants' views of the problem are recorded and shared in an atmosphere that promotes constructive divergence and learning rather than defensiveness and face-saving. Immersing the participants in the model construction process increases the possibility that effective learning occurs (Sterman, 1994). By involving the participants in structured group techniques, GMB attempts to create a common learning experience, where there is not only understanding, but also *common* understanding of a problem, its causes and possible solutions.

By promoting consensus (achieving an agreement on a point of view by means of discussion) rather than compromise (achieving an agreement on a point of view by means of mutual concessions), the group develops a shared vision of reality. A decision based on consensus increases the commitment towards its implementation (Vennix, 1999).

Key to the process is the level of ownership of the group in the model. At all moments the group must feel that the problem is 'their' problem and the model under construction is 'their' model. Lack of ownership affects negatively the commitment of the group towards implementation efforts (Akkermans, 1995).

2.2.2 The GMB practice

In practice, a GMB intervention is done through a series of structured group sessions where key stakeholders meet in order to complete a number of activities where a qualitative and/or quantitative system dynamics model is gradually built (Luna-Reyes et al., 2007). However, although the most salient tangible product of a GMB session is a system dynamics model, it is in the process of building the model where most of the benefits of GMB actually lie. For a successful execution of the process, a team of people, in which each person has one or more particular roles, must support the sessions. In the literature, at least two clear roles can be distinguished: (a) the role of a facilitator, who interacts permanently with a group, eliciting knowledge and structuring the conversations, and (b) the role of a modeler/recorder, who keeps track of all what is being said during the session and reflects back key insights derived from it (George P Richardson & Andersen, 1995; Vennix, 1996).

Involving the participants in the model construction not only requires the support of a group with particular roles, it also requires planning each session ahead, and in general, designing how the GMB project will be. Vennix (1996) presents a series of choices to be made when designing a GMB project: Is system dynamics adequate? Should a preliminary model be used before the first session? Who should be invited to the sessions? Should workbooks or interviews follow the sessions in order to collect more information required for building the model? Once the choices have been made then each session requires preparation. In preparing the sessions, the modeling group must define the roles of each integrant, the agenda and goal for each session, and logistical arrangements such as the location of the room where the sessions will be held and the layout of the room itself during the session.

In structuring the activities to be undertaken during the session, Andersen and Richardson (1997, p. 107) report on the use of "fairly sophisticated pieces of small group processes" called scripts. Each script is an activity with a clear (and documented) definition of purpose, participants, inputs, steps to be executed and outcomes. In this context, a GMB session becomes the execution of a predefined series of scripts, where the output of each is used as the input of the next. Hence, the scripts cover the whole range of steps involved in the model construction: there are scripts for problem definition, conceptualization and exploration of policies, among others. A selection of scripts successfully used in the past have been collected as 'best practices' in a document called *Scriptapedia* (Hovmand et al., 2011). In the usage of scripts, Vennix (1999) warns how giving such a rigid structure to a session may prevent the modeler team to actually fulfill the needs of the group by impeding change as the session develops.

2.3 GMB as an alternative approach for a system dynamics intervention at UMG

From the previous discussion, Group Model Building emerged as a relevant alternative to the previous approach in defining the problem. GMB literature provided methods specifically targeted to the creation of a common problem definition among participants while addressing barriers to learning such as defensive attitudes, and group thinking (Vennix, 1996). Consensus on the definition of the problem was seen as a first step towards a successful implementation of the recommendations resulting from the project. Thus, the problem definition stage of the modeling effort was structured as a GMB session. Once the approach to problem definition was presented to the company's stakeholders, it was suggested that the whole model building process should be framed in the GMB methodology. The goals of using GMB in the project were defined to be:

- To create consensus on the problem definition
- To foster learning by testing the participant's mental models in a simulation model
- To generate as final result a plan for implementation of changes with commitment from the participants.

2.4 Planning the GMB sessions

In order to plan the GMB project, the following considerations were made.

2.4.1 Adequacy of system dynamics

System dynamics have been extensively applied to supply chain management (Akkermans, 2005). Furthermore, the focus of the project was not on optimization but on design of better policies, a field where system dynamics have proven effective (Lyneis, 1980). Hence, system dynamics appeared as adequate to study the supply chain at UMG.

A more detailed review on the adequacy of quantitative simulation is presented in section 4.6.

2.4.2 Preparatory interviews

Preparatory interviews are recommended as a way to get acquainted with the persons who will participate in the sessions and with the problem under discussion and can even be used to build a preliminary model from which the group can start working in the first session (Vennix, 1996). However, such interviews were not conducted for the following reasons: (a) the author was already acquainted with most of the participants, and (b) a critical goal for the first session was to create a shared understanding of the problem. Hence, doing interviews in isolation with each participant was not seen beneficial for that purpose.

2.4.3 Usage of a preliminary model

Although using a preliminary model is a practice recommended for new system dynamics practitioners as an aid to start the building process, an additional analysis was made in view of the level of "messiness[3]" of the problem. While for messy problems, preliminary interviews and the preparation of a preliminary model is highly recommended, the context of the project at UMG suggested that the problem was not as messy. The discussion would likely be (at least at the beginning) around a physical entity (i.e. the supply chain), which appeared easier to model than an abstract concept (such as corruption) where a bigger load of judgments of value and other personal considerations may be involved.

Another point taken in consideration was that that the level the ownership of the group in the model was critical. Since presenting a preliminary model during the first session could affect negatively the ownership of the participants, the author concluded that the risks of loosing ownership surpassed the benefits of easing the process by developing a preliminary model.

[3] A characteristic of a messy problem is that it is a problem where people hold dissimilar views of a particular situation, which results in different problem definitions (Vennix, 1996). The bigger the differences among participants, the messier the problem can be.

The author decided to make use of an intermediate approach by making use of a concept model (G.P. Richardson, 2006), as will be presented in the plan for the first session.

2.4.4 Definition of the gatekeeper and participants

A gatekeeper is a person who "helps to select appropriate people within the organization with whom to work before the workshop, works with the modeling team to plan those pre-workshop meetings, schedules them, and participates in them" (Andersen & Richardson, 1997), recognizing the importance of such role, the author involved, from the beginning of the project planning, the manager responsible for the spare parts operations. The first task was defining the participants. Following (Vennix, 1996), the criteria used to choose who to include was: (a) include people with direct responsibility for the key processes of the spare parts supply chain in order to increase the possibility of implementation and change based on model recommendations, (b) to include people from different departments in order to increase the diversity of views on the problem, and (c) to keep the group below 7 participants, in order to give each participant enough time to provide input to the process and diminish potential problems that may arise with larger groups. As a result, the following list of participants emerged:

- Spare parts manager
- Inventory manager
- After-sales manager
- Finance responsible for spare parts operations
- Logistics responsible for spare parts operations
- Spare parts marketing responsible
- Branch manager

2.4.5 Definition of the goals, scope and products of the work

Andersen and Richardson (1997) recommend providing a clear definition of the goals of the project, its scope and the products that must result from it. The goals were defined already in 2.4. The scope of the work was defined rather broadly to concern the spare parts operations. Further details regarding the scope were left for the sessions in order to avoid restricting from the beginning the topics of discussion.

The products of the project were defined as two-fold:

1. A quantitative simulation model providing insights into the causes of the main problematic situation in the spare parts operations and into possible policies of improvement.

2. A plan of action to carry on the implementation of the recommendations provided

2.4.6 Overall structure of the sessions

The plan was designed to execute the GMB in three sessions, each of them with a particular objective:

1. First session: To create a shared problem definition with the main stakeholders of the spare parts supply chain, and to build a model that represents the past and actual situation of the system.
2. Second session: Based on the modeling results from the previous session and a shared understanding of the causes of the problematic behavior, explore which policies would lead to improvements and how such policies could be implemented
3. Third session: Explore the results of testing the policies proposed in the simulation model and assess which policies should be translated into plans for implementation.

After the company's CEO and relevant stakeholders agreed with the plan designed, the author proceeded with the preparation for the first GMB session, reported in the next chapter.

Discussion

The first session was intended to define the problem and build a model structure representing the actual and historical system behavior. However, the definition of the problem took most of the time available during the first session. Hence, the model construction was delayed until the second session. The policy elicitation originally planned for the second session was delayed until the third session. Assessment of possible policies, which was originally the goal of the third session, would be postponed after the GMB project with a subgroup of the participants. Such assessment was not finally executed due to time constraints.

Chapter 3. First group model building session

This chapter is devoted to describe the activities undertaken in the planning, preparation and execution of the first GMB session. The work around facilitating a GMB session is full of small details and unexpected events. In the current and subsequent chapters devoted to GMB sessions I will attempt to describe a summary of the main issues that arouse. As I mentioned, planning a Group Model Building project involves making choices among the different alternatives on how to prepare and conduct a session. Reasons will be presented for the choices made and their basis in the literature.

3.1 Preparation of the first session

Since some preparations for the first session also apply to the other sessions, preparing the first session included more work than preparing the rest of them. Hence, this chapter will describe plans and arrangements in more detail, while the other chapters about GMB sessions will only describe the differences between them.

3.1.1 Roles of team members

Given the fortunate situation that the author was in company with another system dynamicist with knowledge and experience in GMB, a team of two was formed, in which each played the two main roles of a GMB session: Maria Franco acted as facilitator and I acted as recorder, modeler and reflector[4] in the sessions. This decision was based on a simple criterion: Since I was responsible for building the simulation model, I preferred to be in the "backstage" during the sessions, collecting the mental models described and suggesting courses of action to the facilitator when necessary. The facilitator would lead the group through the model building process. These roles would remain during the rest of the project.

3.1.2 Purpose and agenda

The purpose of the first session was to define the problem to be modeled. Following Andersen and Richardson (1997), the agenda was defined in two levels of detail; a public agenda to be delivered to the participants and a detailed agenda that would include more information for the project team. The agenda developed is presented in Appendix 1. The first (and subsequent) session was planned to last 2.5 hours. The items on the agenda ranged from divergent activities, where participants were motivated to individually

[4] A reflector is the person in charge of providing feedback to the participants during or at the end of the sessions, and provide reflections of the main insights gained during the session.

proposed variables or other ideas to be shared with the group at a subsequent stage, to convergent activities, where the group must choose or decide on a particular variable or problem. The agenda was:

1. Variable list: Define a list of the relevant variables for the spare parts operations as suggested by Hines (2000).
2. Graphs over time script: Select some of those variables and draw graphs over time that explain the historical behavior of each variable as well as the feared and hoped behavior for the future (Hovmand, et al., 2011).
3. Problem definition: From the graphs over time, define the problem to be modeled by the group
4. Concept model script: The team group presents a simple simulation model that introduces the group to the modeling notation and shows how model structure and behavior are linked. Such a model is purposefully incomplete, opening space for participants to offer suggestions on its improvement, which leads the next activity (Hovmand, et al., 2011).
5. Start the modeling task: The facilitator starts eliciting model structure from the concept model presented.

3.1.3 Room layout

The room layout can greatly affect the outcomes of a group session (Andersen & Richardson, 1997; Vennix, 1996). Using guidelines from the literature the room layout was set as presented in Figure 5. In general the seats were organized in V-shape, so that all participants could see each other. In the front of the participants the facilitator would use the wall to paste products of the session and the whiteboard to build the model.

Figure 5. Room layout for the first (and subsequent) GMB sessions

3.2 Activities undertaken during the first session

3.2.1 List of variables

The first activity consisted in defining a list of important variables related to the spare parts operations. Participants were asked to think about the most important variables related to the spare parts business and write them down on a piece of paper. Then, each of them was asked to provide the facilitator with the most important one and explain why it was important. Each variable would be recorded on a whiteboard. After several variables were shared, participants were asked to vote for the variables they considered the most relevant. To vote, they were given small pieces of paper, which they would stick in front of the variable they would like to vote for. After voting, the team would count the votes and highlight the variables that received the most votes. Those variables represented the output of the first activity. A fraction of the whiteboard with the variables and the votes is presented in Figure 6.

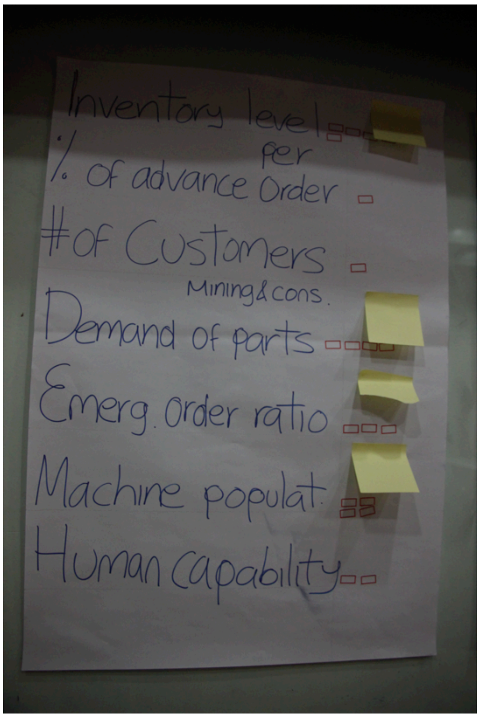

Figure 6. List of variables, with individual votes (in red) and the most voted ones (in yellow)

3.2.2 Graphs over time

Once the variables were chosen, the participants developed the graphs over time for the variables they considered most relevant, and shared their 'dynamic stories' about how that variable have evolved over time, and how it is feared or expected to evolve in the future. Figure 7 shows the graphs over time elicited:

Figure 7. Graphs over time elicited during the session

3.2.3 Problem definition

A discussion after the graphs over time were elicited revealed the most important problems for the group. The problems were recorded on the whiteboard as a memory.

3.2.4 Concept model

In order to introduce the group to the notation of system dynamics and the concepts of stocks, rates and accumulations, the modeler presented on the whiteboard a simple bathtub system and related it to the concepts of system dynamics. Then the similarity with an inventory system was pointed out, in order to establish an association with the spare parts problem. Finally, a simulation model was presented. The model illustrated a simple situation showing how product attractiveness is affected by delivery delay in a single-stock supply chain (Figure 8).

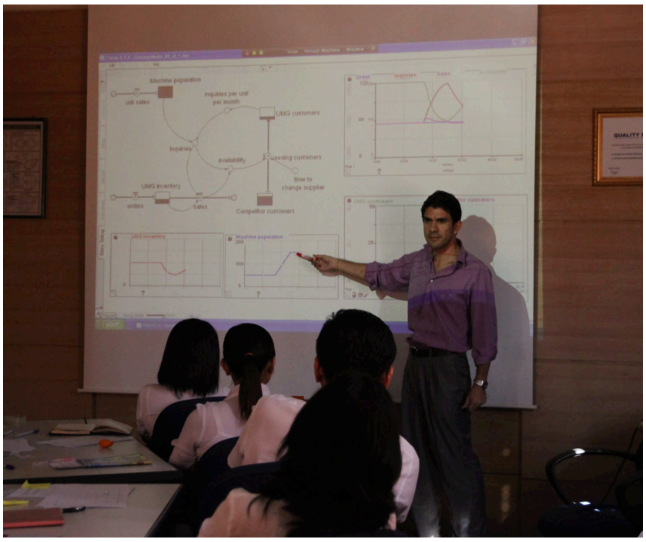
Figure 8. Modeler presenting the concept model to participants

3.2.5 Start of the modeling task

Right after the concept model was presented, the facilitator started the group model-building task. The model was developed on a whiteboard (Figure 9). Given the limited time available, the model resulted in an oversimplified view of the spare parts operations. For this reason, the second session was all devoted to the construction of the model.

Figure 9. Facilitator and participants building the model in the whiteboard

3.3 Products of the first session

The products of the first session were:

- A preliminary model of how stock orders are made at UMG and how they could be related to inventory growth.
- A list of behaviors over time and descriptions that served as reference for the model building process between sessions.
- An initial problem definition.

Based on these products, the author elaborated on the problem definition that would guide the simulation model, and a simulation model covering the causal structure elicited in the session, as will be described in the next two chapters.

Chapter 4. Problem definition

In order to define the most important concerns of the main stakeholders in the spare parts supply chain, the first GMB session followed a series of activities as follows:

1. Develop a list of variables that affect the spare parts operations
2. Prioritize the variables by a voting system
3. Graph the behavior over time of the variables prioritized (reference modes)

4.1 List of variables

The group was explained the concept of a variable and was asked to list the most relevant variables that would impact the operations of the spare parts supply chain. Then the variables were prioritized. The result was the following list of variables:

1. Inventory level
2. Competitor's price
3. Demand of spare parts
4. Installed base of machines (also known as Machine population)
5. Late payments to supplier
6. Emergency orders

4.2 Graphs over time

The script of graphs over time (Andersen & Richardson, 1997) involves asking participants to portray the evolution over time of the variables previously selected. It is important to clarify that the graphs over time developed reflect the participant's perception of the situations rather than data collected from historical time series. After the session, such graphs would be compared with numerical data available. The result of the data analysis would lead to: (a) the definition of graphs over time (usually called reference modes) based on historical data and, (b) the problem definition that would guide the rest of the modeling process.

The following sections present the graphs over time defined by the group:

4.2.1 Inventory level

Inventory level corresponds to how much inventory of spare parts remains at UMG's facilities at any time, either in the HO or in the branches' inventories. An initial discussion was held during the session on the units by which the inventory should be expressed, two opposing views were elicited: (a) monetary units (i.e. USD – U.S. dollars) and, (b) quantity of spare parts. The conclusion of the group was that although the indicator of inventory level in monetary units is often used in managerial meetings, what customers buy from UMG are spare parts, and it is the spare parts quantity in inventory what determines its adequacy to satisfy customer demand. Hence, the group decided to use quantity of spare parts as the unit of measurement.

Figure 10 shows the graph over time for inventory level developed by two participants (called in the graph A and B). The black line represents the historical inventory level (in which both participants agreed). From year 2012, the colored lines represent two forecasts of the future: what the participant hoped (or desired) and what the participant expected to happen in a business as usual situation. The graph does not have numbers on the Y-axis because participants were not able to define the scale. As it was previously mentioned, participants were not used to measure the inventory by the quantity of parts.

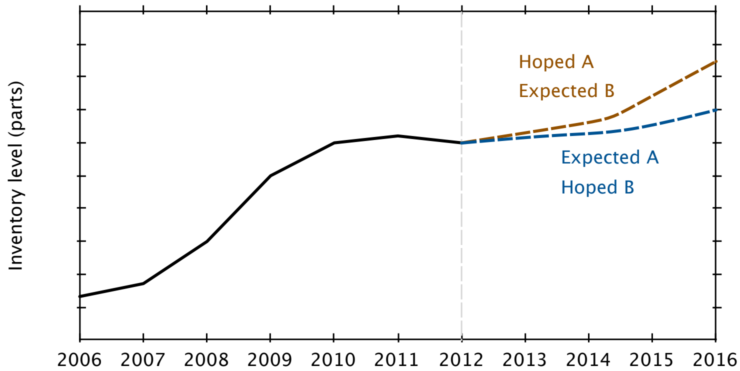

Figure 10. Reference mode of inventory level elicited during the first GMB session

Regarding the historical evolution of the inventory, participants agreed that inventory grew considerably in the period 2006-2010 while it remained nearly constant in the period 2010-2011. However expectations about the future inventory level were divided between two participants: Participant A, who cared mostly about sales profit expected inventory level to remain stable (Expected A in the graph) but hoped (or desired) that it would grow as sales were expected to grow (Hoped A). Participant B, who cared mostly about inventory management hoped inventory level to remain stable or decrease (Hoped B) and expected it would increase (Expected B). Such division was founded on different beliefs of the effect of the inventory on the company's performance: For participant A inventory was seen as an indicator of high sales of parts, while participant B inventory saw it as a burden, an accumulation of parts that could become dead stock if not sold on time. Both points of view were kept as important during the three GMB sessions held.

Discussion

The relation between inventory and sales was related directly to the concept of inventory turnover (sales/inventory). Growth in inventory accompanied with similar growth in sales is desirable (as expressed by participant A). Growth in inventory that is not accompanied by a growth in sales will lead to higher inventory accumulation (as expressed by participant B). Although we realized this during the session, we took the decision of not interfering with the elicitation process at this time but to do it later during the modeler's reflection. However during the first session time constraints did not allow to make such a reflection. It would be done at the beginning of the second session.

4.2.2 Installed base of machines

Parts sales are caused by the usage of spare parts from the machines in the installed base. Figure 11 shows how the participants described the evolution of the installed base in the past (black line) and the expected and hoped behavior in the future (colored lines).

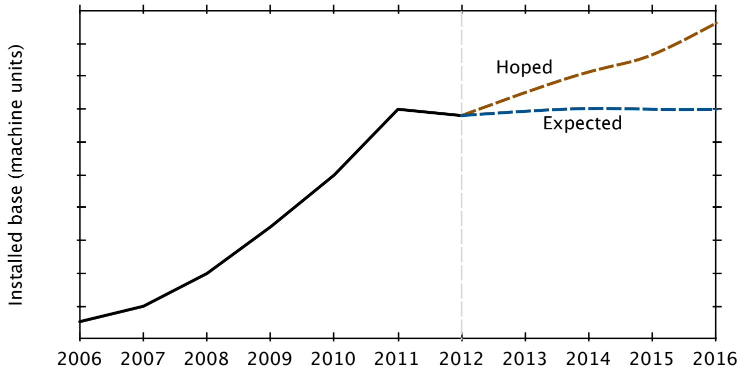

Figure 11. Reference mode for installed base elicited during the first GMB session

According to the session's participants the installed base has been growing from 2006 up-to-date. The growth rate was faster before 2010. After 2010 sales stagnated and the installed base grew more slowly. It is hoped that sales keep increasing in the future although the expectations are that sales will stagnate at the current rate for the next years.

4.2.3 Demand of spare parts

The demand of spare parts represents the total quantity of spare parts required by the machines in the installed base. From that total, customers buy a fraction to UMG (which corresponds to UMG's market share) and a fraction to other companies. Figure 12 shows how participants portrayed the historical demand of spare parts (in black) and the expected and feared behavior (colored lines).

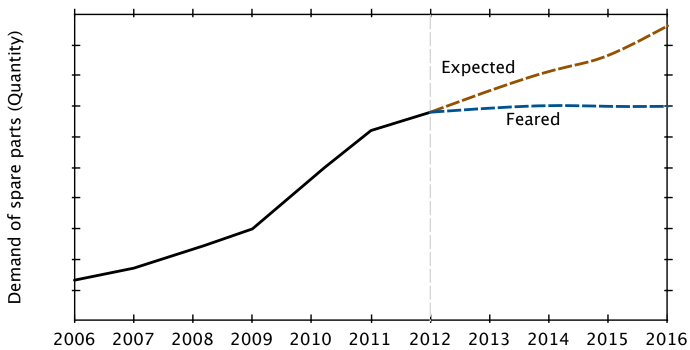

Figure 12. Reference mode for demand of spare parts elicited during the first GMB session

According to the participants, the demand has been growing in the past. The expectation is that it keeps increasing. However, more competitors in the market and slower economic growth lead to fear that demand will stabilize.

4.2.4 Emergency orders

Emergency orders (EO) are orders placed by customers to UMG to import a particular spare part that is not available at UMG's inventory. UMG then places a corresponding order to the supplier to import the spare part and deliver it to the customer. The order is an emergency order because the lead-time for such order is shorter than a normal import lead-time (3 weeks against 4 months). Emergency orders also represent higher costs for the customer due to extra transportation charges.

The amount of emergency orders per month made by customers is also an indicator of availability, since customers exclusively place EO when the spare part is not available at UMG's stock. Had UMG all the spare parts required by customers, EO would be zero.

Figure 13 shows the perception from the participants of the emergency orders (no scale was given to the graph by the participants).

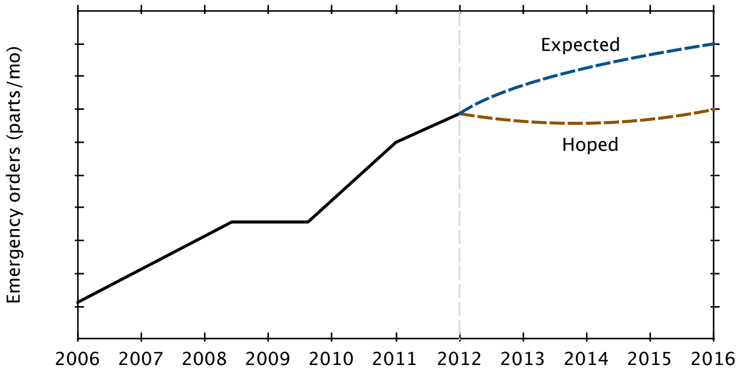

Figure 13. Reference mode for emergency orders elicited during the session

During the last years EO per month has been growing (black line). As a higher amount of EO is seen as an indicator of low availability and low customer satisfaction, the hoped behavior is that in the future EO decrease, however, since no change is planned in the inventory management policies, the expectations are that EO will remain at the same level.

4.2.5 Other variables elicited

Two more variables related to financial indicators were elicited during the session: (a) percentage of discount from competitors, and (b) late payments to suppliers. However, such variables proved subsequently in the project to have little relevance. Hence I will not present further discussion about participant's perceptions on them.

4.3 Reflection from graphs over time

After the group presented the graphs over time, the modeling team initiated a reflection on the variables elicited. The reflection reported how the variables were concentrated on the main dynamics of inventory: Orders, inventory level and parts demand, which in turn affects UMG sales. The team suggested that numerical data would be collected for such variables and the results would be reported at the beginning of the second session.

4.4 Reference modes

Numerical data was collected for the variables discussed in the reflection. For inventory level and parts orders the data was readily available. For the total demand there was not data available. However I considered that the fraction of the demand covered by UMG, that is UMG's sales, would be more appropriate as a reference mode. UMG's sales are directly affected by UMG's operations, while total demand is affected by a series of factors that would enlarge the scope of the project. Choosing UMG's sales had two advantages: (a) it promoted an endogenous approach to the problem, and (b) there were sales data available in the information system. Hence, the third variable chosen was UMG's sales.

I must note that although in the graphs over time the participants provided historical perceptions from 2006 the numerical data was only available from 2010[5]. I recommend the reader to watch the time-scale when comparing the graphs that report the perception of the participants and the graphs that report historical data.

For each reference mode, the historical information was contrasted with the participant's perceptions. Results of the analysis would be reported in the next session and would lead to the final problem definition.

4.4.1 Inventory level

Figure 14 portrays the inventory level for the period 2010-2011. Inventory grew during 2010 from approx. 60.000 parts to almost 100.000 parts (66% increase) and remained in the range of 90.000 to 110.000 parts during 2011. The increase shows three peaks that amount to 5.000 to 10.000 parts. The peaks appear with a period of approx. 8 months. The increase of 66% in the period can be related to the perception of high inventory held by most of the participants (Figure 10).

[5] At the end of 2009 UMG implemented a new information system, from which the data was collected. Due to incompatibilities, historical information was not migrated to the new system.

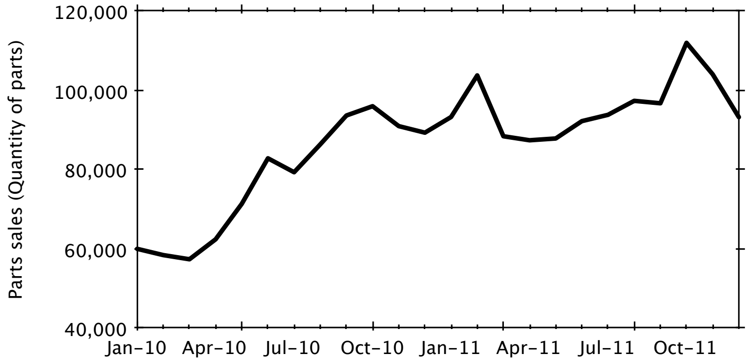

Figure 14. Reference mode of inventory level elicited from available data

4.4.2 Sales

I collected monthly sales data from two different data sets: (a) the company's central information system and (b) the historical files stored at one of the branches. Every branch stores original sales statistics in spreadsheet files and sends periodically the information to the Head Office. The branch selected is the one with the highest participation in the spare parts orders and sales (approx.90% according to company's reports).

Figure 15 shows the two data sets. Sales information extracted from the central system (solid line) and the branch files (dotted line) present similar behavior from Jan-10 to Oct-10. From Oct-10 and Jul-11 the information from the central system reports fluctuations while the information from the branch reports a smooth growth and decline in sales. From Jul-11 ahead both time series coincide again.

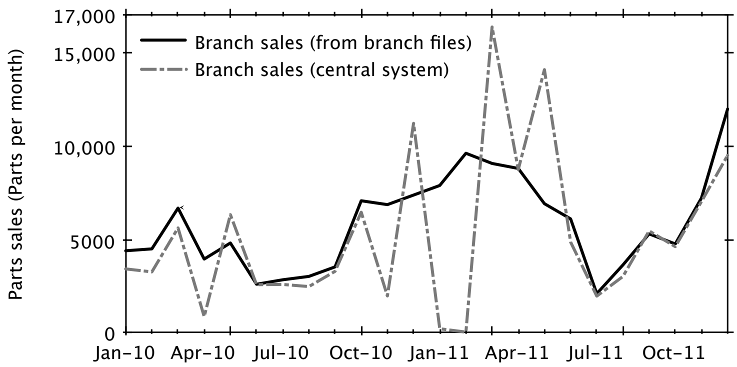

Figure 15. Sales from one branch as registered in the formal and informal systems

Although both represent the same concept (branch sales per month), the graphs differ. I found that branches update their records weekly while the central system is updated monthly. Hence, I decided to use for the project the information reported by the branch, with the assumption that the information from branches would be more accurate and not exposed to the distortions of the data transfer from branches to the central system.

Branch report of sales (solid line in Figure 15) present an increase of more than 100% (from 4800 to 12000 parts/month) during the period under study. However, such increase is not linear, it shows a fluctuation with a peak in Feb-11, suggesting an oscillatory pattern of behavior.

4.4.3 Orders

Unlike sales, custom and emergency orders are registered in the central information system the same day they are placed by the customers. In the case of the stock orders placed by UMG to the supplier, the orders are registered in real-time. Hence, I concluded that regarding orders, the information from the central system was the most accurate available.

Figure 16 portrays monthly emergency orders (solid line). The graph follows an oscillatory pattern of behavior with variable frequency along time. A six-month centered moving average (dotted line) reveals that in average the EO are decreasing over time. In this case, the data does not correspond to the perceptions of the participants (Figure 13). Participant's perceptions described growth in EO.

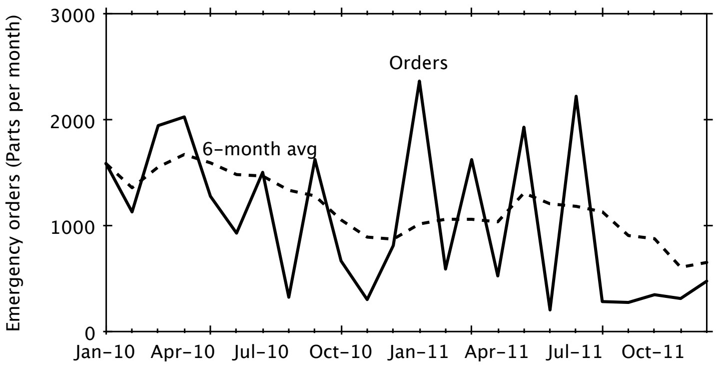

Figure 16. Reference mode for emergency orders elicited collected from numerical data

Besides the emergency orders, I also plotted the stock orders raised by UMG to the supplier. Stock orders are important because they directly influence the inventory levels at UMG. Figure 17 portrays the stock orders over time:

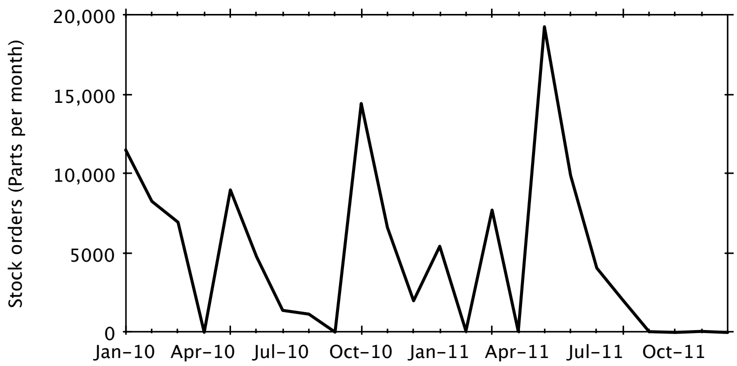

Figure 17. Reference mode for stock orders collected from numerical data

Like emergency orders, stock orders show instability, peaks appear every 5 to 7 months. When the historical behavior was shared with two key participants of the session (spare parts manager and after sales manager), it was received with surprise. Participants were not used to plot orders among their periodical reports. I suggested then plotting the stock orders vs. sales (solid line in Figure 15). However, sales represented the total UMG's sales, including sales from all three types of orders. To make both graphs comparable, I needed to distinguish between sales from each type of order. Although such data was not available, the two participants reported that sales from stock orders accounted for approx. 60% of the total sales. Figure 18 shows a comparison between stock orders (blue), total sales (gray) and estimated sales from stock orders (green).

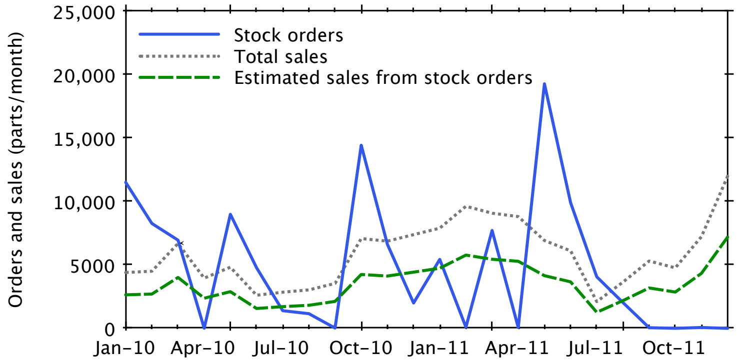

Figure 18. Comparison of stock orders, sales, and estimated stock sales

The graph shows how the fluctuations in stock orders greatly exceed the amplitude of the fluctuations in the sales. When the result was shared with the two key participants it was decided that the amplification and instability in stock orders should be presented to the group in the second session as part of the problem definition.

4.5 Problem statements

From the discussions during the session and posterior feedback provided to (and from) the participants on the numerical data collected for the reference modes, the problem statements were defined as follows:

1. Inventory level has been growing and has reached levels that are believed to be higher than required for the levels of sales.
2. The behavior of orders from UMG to supplier follows an unstable behavior with fluctuations that are higher than the regular fluctuations in sales.

4.6 Suitability of System Dynamics as an approach to the problem definition

Once the problem has been stated, the next question is to confirm if system dynamics was a suitable method to study the situation. To address this question, the problem is analyzed on the light of three phenomena that together makes a problem a good or bad candidate for a system dynamics study:

1. Feedback structure: The main structure of the problem is the spare parts supply chain. Each echelon in the supply chain makes orders to its supplier based on

information of its actual and possible future state. Such orders in turn affect the future state, creating a feedback structure that is replicated across the different actors of the supply chain. It can be asserted that the problem in question is dominated by feedback relationships.

2 Significant delays: Monthly orders from UMG to the supplier take in average 4 months to arrive. Processing the information for the next regular order takes about 1 month. Customers place massive custom orders once per year, expecting the parts to arrive 5 months later. The supplier receives a purchasing plan from UMG once per year. In general, the consequences of each decision across the supply chain are evident several months after the decision was made.

3 Non-linearity: The problem defined states how oscillations in sales and orders are amplified to amplitudes bigger than those of the initial signals from the demand. Inventory have grown to an extent that it is considered out of proportions to the level required by the installed base. The supplier responds with different delivery times according to the order sizes. In general, the supply chain presents phenomena that do not obey a linear relationship between the decision made and the consequence perceived.

With these three phenomena present in the spare parts supply chain, system dynamics appeared to be a suitable methodology to study the problem. Furthermore, a systemic approach that "sees the forest for the trees" was welcomed at UMG, where the day-to-day management of thousands of parts, a hundred of customers and a dozen of suppliers has prevented the stakeholders from discerning overall patterns of behavior and understanding how their own decisions may be creating the problems defined.

Chapter 5. Dynamic hypothesis and model analysis (first iteration)

The final activity of the first GMB session was the construction of a basic model that the group "suspected" was creating the situations described in the problem definition. The author then refined the basic model with additional participant's input, translated it into a simulation model, and presented it to the participants in the next session. In general, the model was constructed in two iterations, each corresponding to the first and second GMB session. Feedback from the participants, numerical data collection and interviews would be used as extra-input during the process.

The present chapter will present the dynamic hypothesis the first iterations.

5.1 Purpose of the model for the first iteration

The purpose of the first simulation model is to reflect the qualitative model built during the first GMB session and to replicate the unstable behavior of stock orders, aiming at providing understanding on the sources of such an instability and its effect on the inventory level.

5.2 Causal structure of the UMG's spare parts supply chain

The model resulting from the first GMB session stipulated a basic inventory control structure. The main goal of the first iteration was to reproduce the unstable behavior found in the sales and orders data. A literature review (Jay W Forrester, 1961; Gonçalves, Hines, & Sterman, 2005; Lyneis, 1980) suggested that a supply chain model with inventory control policies could be a crucial component of the hypothesis. Hence, a deeper study of UMG's supply chain revealed the basic components to begin the modeling effort.

The main decision point identified during the first session was the order placement from UMG to the manufacturer. New orders are placed every month based on the actual inventory and an estimation of future sales. However, the process does not occur instantaneously: The collection of the quantity of inventory available in the branches across the country takes up to one month[6]. Managerial and clerical processes required to process the orders every month take up to two weeks. Once the order is placed, shipping takes 3-4 months until the parts arrive to UMG's facilities. Furthermore, this shipping lead-time is subject to variations due to changing governmental regulations and government-related sporadic events.

[6] Lack of proper communications infrastructure and information systems are the main cause for such delays. An interconnected automated system could potentially reduce them to great extent.

Another important decision point elicited was the ordering process from the final customers to UMG. As customers use their machines, usage causes deterioration in the spare parts, which triggers spare parts orders. Customers keep a quantity of parts in inventory in order to reduce the risks of stock-outs. Hence, their orders are based on forecasts of future usage, their current inventory and their policy to keep safety stock of parts.

Customers experience less delay than UMG in collecting current inventory information, forecasting future usage and processing orders. The most relevant delay for the customer is the delivery time from UMG once the order has been placed.

From the descriptions above, an initial hypothesis is presented in terms of the causal structure in Figure 19.

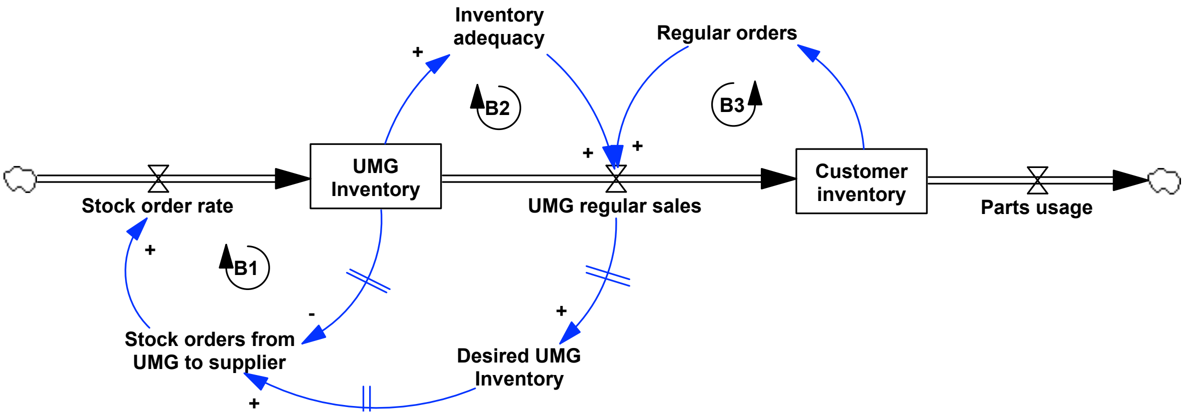

Figure 19. Conceptual stock and flow diagram for initial hypothesis of supply chain instability

The causal structure contains two stocks: the inventory at UMG and the inventory at the customer side. When needed, UMG places stock orders to the supplier (*Stock orders from UMG to supplier*). The supplier then sends the parts to UMG (*Stock order rate*), where the parts accumulate in the *UMG Inventory*. Parts remain accumulated at UMG until customers place a *Regular order*. A regular order causes a *Regular sale* from UMG to the customer, and the parts flow from UMG inventory to the customer's inventory. The customer keeps the spare parts in inventory until the parts are used (*Parts usage*) in the machines.

The structure is governed by three balancing feedback loops (B1, B2, B3). Balancing loop B1 comprises the basic control mechanism used by UMG to keep its inventory at the desired level. As *UMG inventory from SO* is depleted, *Stock orders from UMG to supplier* increase in order to raise the inventory to the desired level. The orders made will eventually increase *UMG inventory*. Hence balancing the effect of the original depletion. The *Desired*

UMG Inventory is defined by the regular sales. Hence, regular sales set the goal for the feedback loop B1. The higher the regular sales, the higher the goal rises[7].

Balancing loop B2 represents the natural mechanism of control that allows having sales only as much as there is inventory available. Any increase in *UMG sales* leads to lower *UMG inventory*, decreasing the *Inventory adequacy.* Lower inventory adequacy affects negatively sales, balancing the original increase.

Balancing loop B3 links the main inventory control at the customer's side to UMG's sales. Higher *Usage of spare parts*, causes depletion of the *Customer inventory*. Lower customer inventory increases *Regular orders,* which increases *UMG regular sales*. As parts are delivered, *Customer inventory* increases, balancing the original depletion.

Besides the polarities, delay marks have been placed in the causal links that present relevant delays. From the system dynamics literature (J. W. Forrester, 1990) it is known that a structure of balancing feedback loops with delays is likely to generate oscillatory behavior. Such behavior is in accordance with the unstable behavior in orders that the current hypothesis is trying to generate. Thus, there is enough confidence to proceed with the formalization of the current hypothesis into a simulation model.

5.2.1 Model boundary for the first iteration

Defining the model boundary helps to maintain the scope of the modeling process under the parameters defined by the purpose of the model (Sterman, 2000). For the model built during the GMB session, the main model boundary can be defined according to which types of orders must be included in the simulation model.

The purpose of the model is related to order instability and inventory accumulation. The participants have revealed that inventory at UMG accumulates mainly from stock orders. Customer and emergency orders placed by clients are delivered as soon as they arrive from the supplier. Hence, the model will include only the stock orders from UMG to supplier and the regular sales from UMG to the customer.

The following model boundary chart summarizes which variables are to be considered endogenous, which exogenous and which are excluded:

[7] Following the causal links in the figure may lead to distinguish a reinforcing feedback loop: an increase in sales raises the inventory goal, increasing the inventory, the inventory adequacy and finally leading to more sales. However, such a loop does not exist. It is not correct to say that by having more inventory adequacy sales will directly increase. A reinforcing feedback may appear if a variable related to the product attractiveness is included. Then, the more adequate the inventory, the higher would be the attractiveness and the higher the sales. Product attractiveness was considered out of scope for the current model purpose.

Endogenous	Exogenous	Excluded
Stock orders from UMG to supplier	Regular orders from customers to UMG	Custom and emergency orders from UMG to manufacturer Custom and emergency sales Uncertainty in order lead-time Manufacturers production and delivery policies Effect of UMG's financial capability on supply from the manufacturers Any effect of UMG's delivery delay or other variables on demand

Table 1. Boundary chart for the model of the first iteration

Only stock orders to the manufacturer will be captured endogenously. The model will be driven by exogenous time-series representing different patterns of orders from customers. The remaining two types of orders are excluded to all extent. All uncertainties in ordering lead-time are also excluded, as well as any possible effect from delays in production or delivery from manufacturers. Finally, any effect of UMG's financial capability on the supply from manufacturers will also be excluded. In term of the causal diagram presented in Figure 19, loops B1 and B2 will be endogenous. Loop B3 is not included because *Regular orders* is the exogenous input of the model.

5.3 UMG's ordering policy to manufacturers

In order to build a formal model of the structure presented, it is necessary to conduct a more detailed study of UMG's policies for stock orders (the main endogenous component of the model).

5.3.1 First elicitation of UMG's ordering policy for stock orders

Eliciting the stock ordering policy used by UMG to place stock orders to the supplier involved a lengthy process of confrontation between the verbal input from key participants and the numerical data available. Describing the whole process here would be too tedious. However, totally omitting it would obscure interesting insights that would become useful at a later stage. Thus, a summary is presented in the following paragraphs.

The first action taken to elicit the details of the policy was to interview the person responsible for inventory control at UMG Head Office. In that interview the officer explained how the ordering policy from UMG was based on a calculation provided by one of the manufacturers. The calculation is embedded in a spreadsheet application that uses monthly input about sales and inventory to propose a quantity to order for each spare part every month. Unfortunately no documentation was available that could shed light in the formulas involved. However, an examination of the spreadsheet revealed that the calculation resembles that of a "fixed-time period model with safety stock" (Jacobs, Chase, & Chase, 2010, p. 373). A more detailed description of such model is presented in Appendix 2.

In order to assess to what extent the policy elicited was the actual policy in place, two sets of numerical data were compared: (a) numerical data listing how many parts the policy suggested to order for each spare part every month, and (b) the actual monthly orders placed. If the ordering policy described were the actual policy in use, both sets should match in the quantity of parts ordered per month (at least approximately). However, the comparison revealed an important difference. To demonstrate this fact, Figure 20 portrays the two sets of data previously compared.

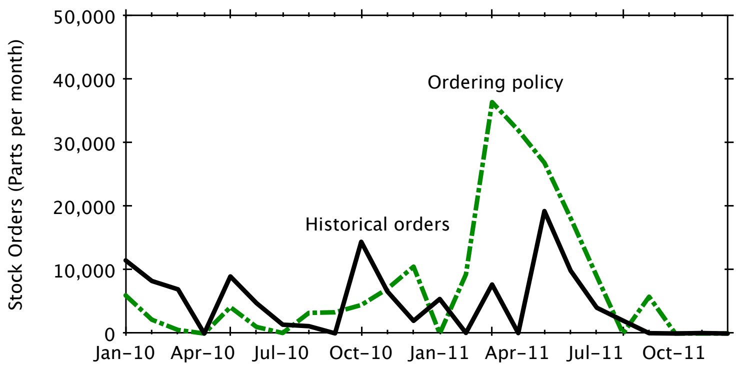

Figure 20. Comparison of UMG's ordering policy with the actual stock orders

Both curves differ by several thousands of parts in various periods of time. At times, the historical orders were higher than what was suggested by the ordering policy, at other times historical orders were lower. Although both curves present instability, it cannot be concluded that the historical orders have obeyed the ordering policy registered in the spreadsheet. Hence, the author's conclusion is that UMG's orders to suppliers were not based (or at least not only based) on the policy described before.

I presented Figure 20 to the same person who described the previous ordering policy. The conclusion obtained was that the result of the "fixed-time period model" is not directly used to place orders, but it passes through an adjustment process. Such process attempts to correct what at that moment was described as a "sometimes faulty calculation". At this point the author realized a new policy needed to be revealed.

5.3.2 Second elicitation of UMG's ordering policy to the manufacturer

The second round of elicitation revealed the final result from the spreadsheet ordering model is totally overridden by the "adjustment" made after. In practice, the person responsible for placing the orders uses the partial calculations offered by the spreadsheet but states the final quantity to order in a different column that has no relation with the result of the "fixed-time period model".

I concluded that eliciting the policy that is followed during the "adjustment" would lead to the actual UMG's ordering calculation. The second policy elicited can be summarized by the following calculation:

$$Order\ qty = (inventory\ coverage\ gap) * expected\ sales + \ safety\ stock + backlog$$

Where:

$$inventory\ coverage\ gap = (D - A)$$
$$expected\ sales = \bar{d}$$
$$safety\ stock = T\bar{d}$$
$$backlog = b$$

Then:

$$q = (D - A) * \bar{d} + \overline{Td} + b$$

$$q = \left(L - \frac{(I + IT * r)}{\bar{d}}\right) * \bar{d} + T\bar{d} + b$$

Equation 1. UMG's Ordering policy for stock orders

Where:

$$D = \ Desired\ inventory\ coverage$$
$$A = \ Actual\ inventory\ coverage$$
$$\bar{d} = \ Forecast\ average\ demand\ (weighted\ average\ demand\ of\ last\ six\ months)$$
$$b = \ Order\ backlog\ (orders\ pending\ to\ be\ fullfilled)$$
$$T = \ Time\ between\ reviews\ (1\ month)$$
$$L = \ Lead\ time\ (time\ between\ placing\ an\ order\ and\ receiving\ it)$$
$$I = \ Current\ inventory\ level$$
$$IT = \ Inventory\ in\ transit$$
$$r = \ Reliability\ of\ inventory\ in\ transit\ (50\%)$$

The policy has three components:

1. Order to keep the inventory coverage to the desired level (*Inventory coverage gap*expected sales*): The concept of inventory coverage describes for how long the current inventory will be positive for a constant level of sales. The desired inventory coverage is made equal to the expected lead-time: 4 months. The actual inventory coverage depends of the current inventory level and the inventory in transit. However, given uncertainties in the shipment and import process, not all the inventory in transit arrives at the expected lead-time. Hence, not all the inventory in transit is taken into account when ordering.

About half of the inventory is believed to arrive on time, so the inventory in transit is multiplied by a fraction of 0.5. Once the desired and actual coverage are calculated, the gap between them is multiplied by the forecast of the average demand. This amount corresponds to the forecasted level of sales during the last six months.

2. A *safety stock* equal to the amount of spare parts required to supply the forecasted demand during the period between orders (1 month).
3. A correction for orders pending to be fulfilled, that is, the *backlog* of orders.

Unfortunately, as mentioned before, this policy is taken as an adjustment to the "fixed-time period" model. Hence, the calculation process is not documented in the ordering process; it is done merely by mental calculations. Only the final result, which is the actual amount ordered, is documented (green line in Figure 20).

5.4 Simulation model

A simulation model was built based on the information elicited and numerical data collected. The simulation model would be presented to the participants as a point of departure in the second GMB session. This model captures the ordering policy from UMG to the manufacturer, that is, the feedback loops B1 and B2 presented in 5.1. As discussed in the model boundary section, the ordering policy from the customer to UMG is exogenous in the model. Thus, loop B3 is not included.

5.4.1 Time horizon

The time horizon for the simulation will cover the historical period for which numerical data is available (January 2010 to December 2011) and the study of future behavior from January 2012 to December 2015. January 2010 was chosen because most verbal and numerical information can only be reliably traced back to this date. December 2015 was chosen based on the expectations of the participants during the GMB session: Any improvement to be introduced in the spare parts operations was expected to materialize in verifiable results in the next 3 years. Given that most of the delays in the system are measured in few months, 36 months appeared as adequate in order to display the transient and non-transient response of the model to different scenarios.

5.4.2 Ordering policy from UMG to the manufacturers

The ordering policy (described in 5.3.2) have been restated as follows (IIT stands for *inventory in transit* and IOH stands for *inventory on hand*):

$$Order\ quantity = (Desired\ IIT - Actual\ IIT) + (Desired\ IOH - Actual\ IOH) + Safety\ stock + Backlog$$

Where:

$Desired\ IIT = L * \bar{d}$

$Actual\ IIT = IT * r$

$Desired\ IOH = T * \bar{d}$

$Actual\ IOH = I$

$Safety\ stock = \bar{d}$

$Backlog = b$

Then:

$$q = \left(L * \bar{d} - IT * r\right) + \left(T * \bar{d} - I\right) + \bar{d} + b$$

Equation 2. UMG's stock ordering policy restated

By reordering the equation in these terms, the calculation can be grouped in four components:

1. An adjustment for inventory in transit ($L * \bar{d} - IT * r$).
2. An adjustment for the inventory on hand ($T * \bar{d} - I$).
3. A safety stock component that in practice plays the role of replacing the actual sales rate in order to avoid a steady state error $\bar{d}$.
4. An adjustment for orders pending to be fulfilled, that is, the backlog of orders b.

The sum of the four components is the order quantity. The order quantity is the gap that needs to be closed for inventories to (a) reach their desired values, (b) cover the safety stock and (c) correct any excess of backlog. The gap is then divided by the inventory adjustment time to obtain the actual order rate. The adjustment time is one month. Stock orders are placed monthly.

This ordering model is in agreement with supply chain models in the literature (Sterman, 2000, p. 670). Once the main physical flows and decision points were identified, I developed the stock and flow structure.

5.4.3 Stock and flow structure

The stock and flow structure is presented in Figure 21.

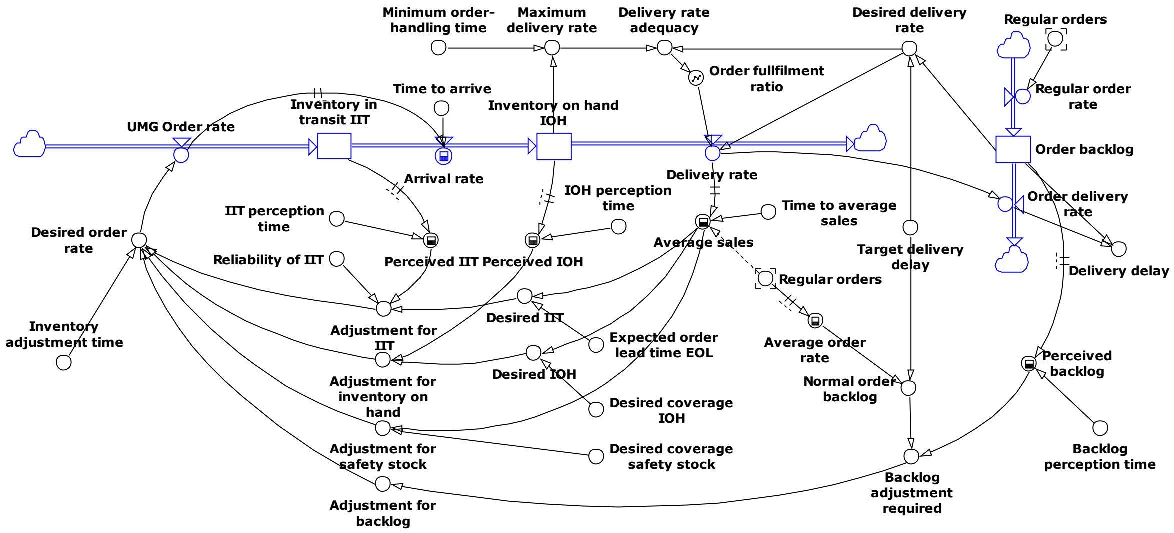

Figure 21. Stock and flow structure of the ordering policy from UMG to manufacturers (first iteration)

Regular orders represent the regular orders received from the customer (custom and emergency orders excluded). Orders are accumulated in an *Order backlog*. The backlog and the *Target delivery delay* set by UMG determine the *Desired delivery rate*, which is the rate to which UMG is committed to deliver the parts to its customers. The actual *Delivery rate* is equal to the *Desired delivery rate* provided there is enough inventory. The adequacy of the inventory (*Delivery rate adequacy*) is set in terms of the ratio of the *Maximum delivery rate* (given by the current inventory level) to the *Desired delivery rate*.

A *Maximum delivery rate* equal to the *Desired delivery rate* could mean that in the aggregate there is just enough inventory to cope with the current level of demand. In the situation that UMG distributed one type of spare part in one branch this would be the case. However, two facts make such situation impossible:

- Heterogeneity among items: UMG distributes around 2500 different items. From these items, around 500 are regularly maintained in stock. The items maintained in stock vary from O-Rings, which are small plastic rings used in hydraulic connections, to filters and electrical components. Most of these items have a different frequency of replacement in the machines, different costs and market share.
- Parts are sold in more than 10 branches across the country. Each branch is responsible to supply a fraction of the installed base.

Hence, even if the total aggregate demand could be forecasted, keeping inventory just enough to fulfill such demand would lead to insufficient supply to customers. The reason is well-known in the inventory models literature: “When many items are aggregated, some individual items are likely to be out of stock even when the aggregate desired shipment rate equals the maximum shipment rate” (Sterman, 2000, p. 712). It is impossible to predict which items will be ordered to which branch even if an aggregate quantity of items can be estimated, thus, a non-linearity is introduced in the model to address such phenomenon: the *Order fulfillment ratio*. The fulfillment ratio is described as a graph function of the *Delivery rate adequacy* (Figure 22)

Figure 22. Graph function for the delivery rate adequacy

An adequacy of 1 means that inventory is just enough to fulfill the demand in the aggregate. It was estimated that when adequacy equals 1, only around 60% of the orders could be fulfilled. Only by having in the aggregate more than twice the inventory the chance of not fulfilling the inventory is negligible, resulting in 100% of the orders fulfilled.

The *Delivery rate* of the last 6 months is averaged in *Average sales*. *Average sales*, *Inventory on hand* and *Inventory in transit* are used to calculate the quantity to order (*Desired order rate*). However, the perceived value of the inventory in transit and inventory on hand lags their real value by a time delay[8]. Information arrives to the ordering decision point with a delay that was estimated by the participants in 1 month (*IIT perception time* and *IOH perception time)*. *Average sales* and perceived values of inventory are then used to calculate the desired inventory in transit (*Desired IIT*) and desired inventory on hand (Desired IOH). Once the desired inventories are calculated, the quantity required to adjust the perceived inventories to their desired values correspond to the first and second adjustment (*Adjustment for IIT* and *Adjustment for IOH*) described in 5.4.2.

The last two adjustments included in the ordering calculation are the *Adjustment for safety stock*, which aims at the replacement of the actual perceived sales, and the Adjustment *for backlog*. Given a *Target delivery delay*, there will always be a *Normal order backlog,* that is, a backlog that will remain even if the actual delivery delay matches the *Target delivery delay*. The backlog is normal because it allows for the *Delivery delay* to be equal to the *Target delivery delay*, a delay that customers accept waiting for without negative consequences in the future sales. The *Perceived backlog* lags the actual backlog

[8] Counting the inventory is done manually, Myanmar's infrastructure conditions do not allow for real-time connectivity between branches (where the inventory is) and Head Office (where the decisions are made), even worse, the information system is not trusted among key officers.

for a period of 1-2 months, time taken to collect the backlog information from all branches and consolidate it at the Head Office. When the *Perceived backlog* rises over the *Normal order backlog*, the excess must be compensated by higher delivery rates. Higher delivery rates must be compensated themselves with higher orders. Such adjustment corresponds to the *Adjustment for backlog*.

Finally, the *Desired order rate* is calculated from the sum of *Adjustment for IIT*, *Adjustment for IOH*, *Adjustment for safety stock* and *Adjustment for backlog*, as presented in Equation 2.

The orders placed by UMG cause parts delivered by the supplier to enter the *Inventory in transit* (IIT). After a *Time to arrive, the parts* are received and enter the *Inventory on hand*. (IOH)

5.4.4 Parameter values

Although statistical estimation from numerical data is advisable as the first method to estimate the value of the model parameters (Sterman, 2000. Pg. 867), the author decided for the first iteration of the model to use solely estimations from interviews to key group participants. Developing the simulation model as similar as possible to the model built by the group during the GMB sessions is key to the ownership participants have to the model (Vennix, 1996). Ownership is a critical factor of success for a GMB modeling effort (Vennix, 1996), the author decided to keep the same parameter values suggested by the group. In that way, the group could test on the model the assumptions of the values used and the ownership would not be potentially endangered. The parameter values were defined as follows:

Model parameter	Value
Backlog perception time	2 months
Target delivery delay	0.125 months (1/2 week)
Time to average sales	6 months
IOH perception time	1 month
IIT perception time	1 month
Expected order lead-time EOL	4 months
Desired inventory coverage	1 month
Desired coverage safety stock	1 month
Reliability of IIT	50%
Inventory adjustment time	1 month
Time for IIT to arrive	4 months
Minimum order-handling time	0.5 week

Table 2. Initial conditions for parameters

5.5 Model validation

A basic set of tests aiming at verifying that the model structure was free from formulation errors was made. Tests included extreme condition tests and "loop-knockout" tests. More detailed tests were postponed for a later iteration of the model. The main reason was that the model was highly aggregated and simplified, so it would likely be heavily modified in subsequent iterations. Furthermore, the model structure strongly resembles that of the classic generic supply chain model of Jay W Forrester (1961) for which basic validity tests have already been made. In this iteration stronger emphasis was put in the analysis of the model behavior, as it would be part of the feedback given to the participants in the second GMB session.

5.6 Analysis of model behavior

In order to explore the behavior of the stock and flow structure, the simulation model was tested under various scenarios for the *Regular orders* placed by customers (the only exogenous variable of the model). Regarding the scenarios to define for *Regular orders*, (Lyneis, 1980, p. 102) suggests the following types of inputs:

- Pure disturbances to the model initialized in equilibrium such as step input, pulse input, noise, cyclical, and growth or decline.
- Seasonal orders
- Historical orders

From the tests suggested, those which the author considered more relevant, were executed. The results are presented below.

5.6.1 Stimuli to the model initialized in equilibrium

Below is presented an analysis of the model response from equilibrium to different regular order inputs. The analysis is based on the causal structure and the loops presented in (Figure 19).

5.6.1.1 Constant regular orders

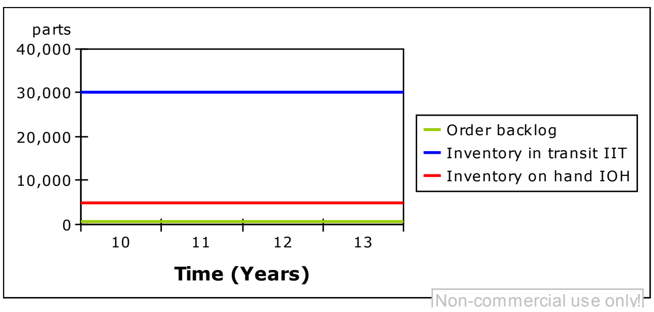

Figure 23. Response of the model to constant regular orders

Evaluating the model behavior under a simple constant input allows to study the values that the stocks would take if the system were in pure equilibrium. Figure 23 shows how the inventory in transit is 6 times higher than the inventory on hand. Meaning that the actual policy would imply a strong investment from UMG in inventory in transit compared to the actual inventory in the warehouses.

5.6.1.2 Step increase in regular orders of 20%

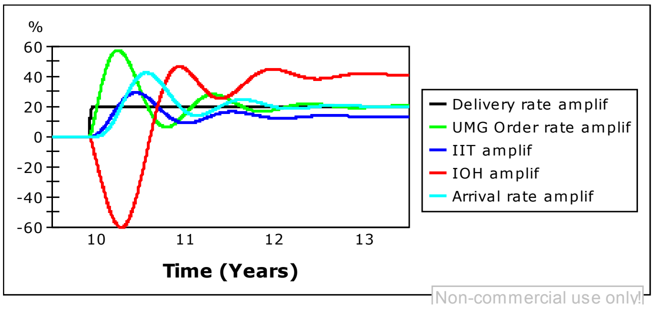

Figure 24. Response of the model to a 20% step increase in regular orders

A step increase in regular of 20%, creates damped oscillations in the system. Figure 24 shows the degree of amplification from the equilibrium values for key variables. Initially, as regular orders increase (not shown) The delivery rate (regular sales) increase (black line) activating the feedback loop B1: Higher deliveries deplete the inventory on hand (IOH, red line), that then decreases to 60% of its original value three months later. As IOH decreases, stock orders to supplier (UMG order rate, green line) are placed in order to adjust the IOH. However the adjustment is not materialized immediately. It takes 4 months for the inventory in transit (IIT) to arrive, a time period during which IOH has been decreasing even more. Furthermore, due to the information delays and the recognition of only 50% of the inventory in transit, more parts are ordered than what is required, causing an overshoot in the IIT (27%) at the end of year 10 and eventually in the IOH (45%) at the middle of year 11. In order to compensate for the excess of IIT and IOH, orders decrease below the new delivery rate. Because IIT has a smaller amplification than IOH, it decreases faster to the normal amplification level of 20%, reaching 10% at its lowest point. Declining IIT and IOH cause the order rate to increase again, starting the cycle once more.

Loop R1 causes the *Desired UMG Inventory* (not shown) to increase gradually until *UMG Inventory* reaches the new desired value for the increased level of sales.

By the second period of the oscillation (around year 12) the system has reached a new equilibrium. Damped oscillations demonstrate that the system is dominated by balancing feedback loops under this scenario.

5.6.1.3 Cyclical sales with a peak amplitude of 20%

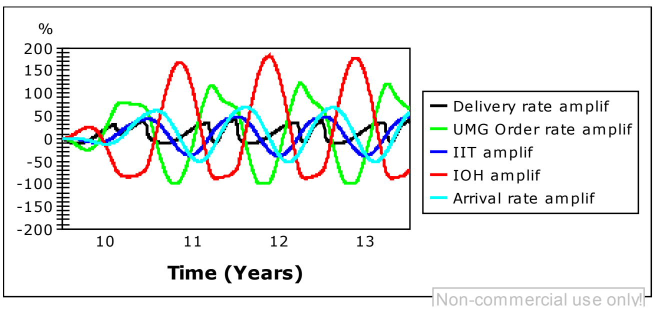

Figure 25. Response of the model to cyclical regular orders of 20%

A cyclical signal of regular orders produces cycles on the system. Figure 25 shows how amplification in the delivery rate of 20% produces amplifications in the inventory on hand of 168% over the equilibrium value and of 80% under the equilibrium value. Fluctuations downward are not as deep because the inventory reaches zero level at the bottom of each oscillation. From this analysis I derived that the ordering policy is highly reactive to seasonal changes in demand. The order rate is amplified by more than 100%. Such behavior was similar to the one observed in the reference modes section.

Given that the purpose of the first iteration of the model was to present to the participants of the GMB session a dynamic explanation for instability in orders, the behavior and analysis obtained so far was the main result fed back to the participants during the second GMB session.

Discussion

The modeler noted a similar pattern of behavior between the model and the historical data regarding the amplification of orders vs. sales. However, I also noted that the pattern of behavior of the inventory was not similar at all. In the simulation, the inventory oscillates, while in the historical data the inventory presents a much smoother behavior.

Given that the output of the simulation model did not resemble the historical behavior of the variables under study, I refrained from using and presenting the model as if it were a representation of reality. For the session, I presented it as a representation of the stock ordering policy as key participants described it to me.

Chapter 6. Second group model building session

This chapter is devoted to describe the activities undertaken for the second GMB session.

6.1 Preparing the second session

Many aspects of the preparation for the second session remained unmodified from the first session. The roles of the team members remained. The agenda was developed in a fashion similar to that of the first session. The second session was again intended to last 2.5 hours. The room layout was kept equal as well.

6.2 Purpose of the second session

The purpose of the second session was to develop a more complete model that could potentially reproduce the actual problematic behavior as presented in the reference modes and described in the problem statements.

6.3 Activities undertaken during the second session

6.3.1 Feedback to participants of the work done between sessions

Following (Vennix, 1996), the first activity of the second session was to provide feedback to the participants on: (a) the information collected for the reference modes, (b) the problem definition and (c) an introduction to the stock ordering policy and how it was elicited.

6.3.2 Presentation of the simulation model

The modeler presented the simulation model built from the structure elicited during the first session supplemented with data collected, and presented conclusions of its behavior. The structure of the simulation model was a refined version of the structure elicited during the first session. However, the modeler kept the quantity and the names of the variables as similar as possible to the model built by the group in order to maintain the ownership to it.

6.3.3 Model building

The facilitator continued the model-building task starting at the end of the first session departing from a copy of the simulation model on the whiteboard.

6.4 Products of the second session

The product of the second session was the stock and flow model presented in Figure 26.

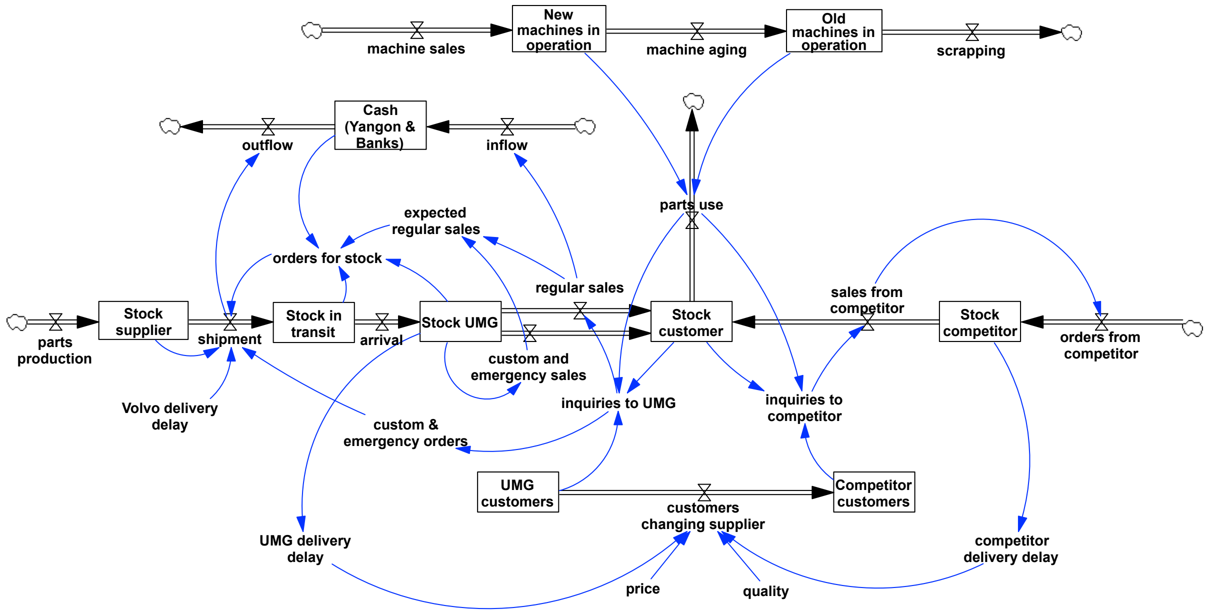

Figure 26. Stock and flow diagram resulting from the second session

The model covered an ample scope of the spare parts operations:

- Installed base of machines: The installed base was represented by a simple aging chain (top of the figure). Sales of new machines accumulated in a stock of new machines in operation. After some time, machines in operation would become old machines in operation, to be finally depleted by machine scrapping.
- Customers: The population of total customers of machines was divided into two stocks (bottom of the figure): UMG customers and competitor customers. It was agreed that customers changed between suppliers according to three criteria: Delivery delays, price and quality of the spare parts.
- Supply chain: The main spare parts supply chain (center) included the inventory at the supplier, inventory in transit, inventory at UMG, inventory at the customer and the inventory from the competitor. Also, the three types of orders were included in the supply chain: Regular orders as an outflow of the stock of UMG inventory, and custom & emergency orders as orders that are first redirected to the supplier (*custom & emergency orders*) and later delivered when the parts arrive at UMG inventory (*custom & emergency sales*).
- Finance: A financial component was included, representing the main inflows and outflows of cash from the spare parts operations.

At the end of the session, the modeling team agreed with the participants that the simulation model would include a subset of the structure created in the whiteboard. That is, structure that may be relevant for the main purpose of the project, To understand the causes of high and growing inventory and order instability, and to find out strategies to improve such situations. The analysis of the simulation output from the new model (second iteration) would be the opening activity of the third session.

Chapter 7. Dynamic hypothesis (second iteration)

7.1 Purpose of the model for the second iteration

The purpose of the simulation model in the first iteration was to provide understanding on the sources of instability in stock orders. The model showed how a stock ordering policy based on past sales, and the interaction with information and material delays could result in oscillatory behavior. However, the model was an over simplification of the actual workings of the UMG's spare parts operations. Thus, based on the results from the expanded model elicited during the second GMB session, the purpose of the second simulation model extended the purpose of the first iteration as follows: To provide an explanation on how UMG's stock ordering decisions generate instability on stock orders to supplier and higher-than-desired levels of inventory.

7.2 Refinement of the scope for the simulation model

The model elicited in the second session (Figure 26) covers an ample scope. To which extend each piece of structure helps to explain the growing inventory and instability in orders? It has been said that "The art of model building is knowing what to cut out" (Sterman, 2001). In this case, it was critical to define which components of the model would lead to endogenous explanations of the problem definition and serve the purpose of the model. In particular, the structure elicited in the second session revealed two potential sources of instability:

1. The formation of expected regular sales is based on the sum of regular, custom and emergency sales. This situation is represented in Figure 26 by the two causal links reaching *expected regular sales*. One causal link from *regular sales*, and another from *custom & emergency sales*.
2. The total inventory (stock of parts arriving from regular, custom and emergency orders) is used as a source of information for the calculation of the stock orders. This situation is reflected in Figure 26 in the causal link from *Stock UMG* to *orders from stock*. Although during the session it was not explicit that the stock was composed of the parts arriving from the three order types, further inquiry to key participants confirmed that it was the case.

From the whole structure elicited during the second session, the author hypothesized that these two situations may be important drivers of instability. Hence, the simulation model for the second iteration would focus on their dynamic consequences and their effects on the inventory level.

7.3 Relevance of custom orders

From the three types of orders made by customers to UMG (*regular, custom, emergency*), the causal structure elicited during the first GMB session included only *regular* orders. The reason was that these were the only type of orders that were believed to affect UMG's inventory. However, during the second GMB session, participants recognized the relevance of the two other types of orders in terms of the volume of parts involved. In particular, custom orders account for an important fraction of the total orders and sales. Figure 27 shows the percentage of spare parts ordered for each type of order.

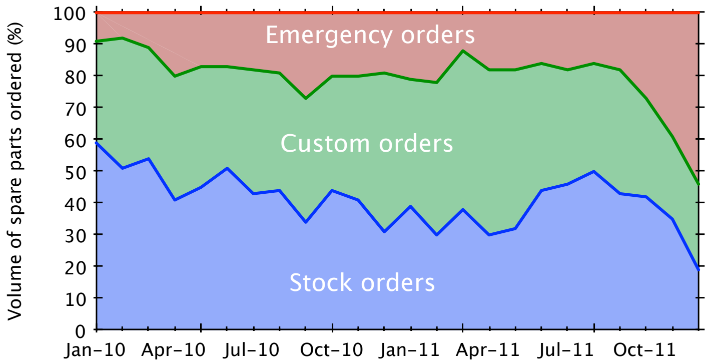

Figure 27. Percentage composition of orders made to the principal by order type

The blue, green and red fill zones represent the percentage of stock, custom and emergency orders from the total of orders made. It can be seen how stock orders cover around 40%-60% of the total orders per month, and custom orders cover another 40%-60%. Emergency orders cover from 10% to 20% except for the last 4 months of 2011. During those months, the machine operations were reduced more than 50% due to internal political problems in Myanmar. Orders for spare parts were almost totally reduced. Only critical parts were ordered during those months, which explains the predominance of emergency orders. However, such disruptive situation cannot be interpreted as part of a pattern of behavior. It can be better understood as a sporadic event.

7.4 Causal structure

Custom orders are quite relevant in terms of volume of parts involved in the operations. To what extend may custom orders affect the overall inventory and stock ordering behavior? Figure 28 expands the structure built during the first iteration (Figure 19) by introducing the interaction between custom orders and the stock orders supply chain:

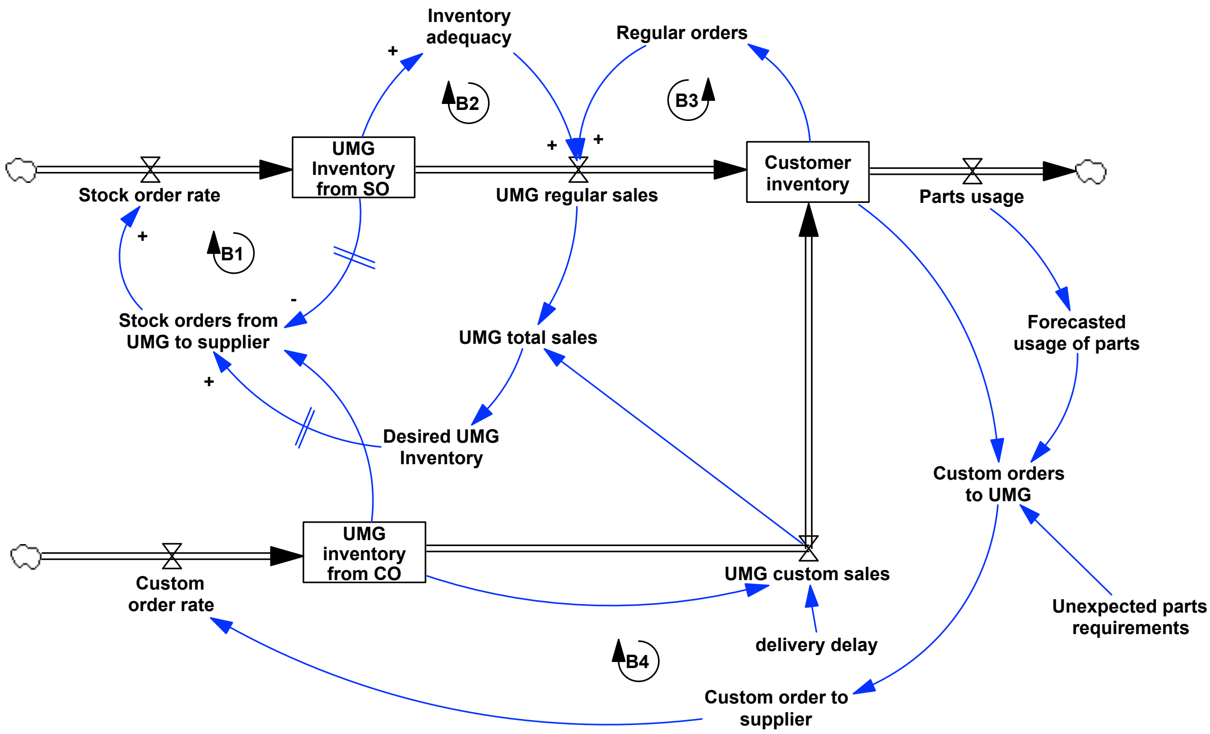

Figure 28. Initial causal structure of the simulation model for the second iteration

The supply chain of spare parts has been divided into two parallel supply chains:

7.4.1 Custom orders supply chain

The supply chain for custom orders and custom sales is presented in the lower section of Figure 28. Customers place custom orders (*Custom orders to UMG*) based on parts usage forecasts, unexpected parts requirements and customer's own inventory. The orders are received by UMG. Unlike regular orders, custom orders are not supplied from UMG's inventory but are directly raised to the supplier (*Custom order to supplier*). The supplier then delivers the spare parts to UMG (*Custom order rate*). The parts arrive to UMG and temporarily accumulate in inventory (*UMG inventory from CO*). After a short *delivery delay* the parts are finally being delivered to the customer (*Custom sales*).

The new custom order structure adds a new balancing loop B4, which corresponds to the inventory control loop used by the customer to control the inventory and the orders. Lower inventory triggers new orders, which in turn triggers more orders reception, increasing the inventory and balancing the original effect.

7.4.2 Stock orders supply chain

The supply chain for stock orders and regular sales is presented in the upper section of Figure 28. The structure have been maintained from the one developed for the first iteration (Figure 19) except for two important adjustments in the ordering policy:

7.4.2.1 Desired inventory calculated from total sales

UMG total sales includes *UMG custom sales* and *UMG regular sales*. Total sales are in turn used to calculate the *Desired UMG inventory*. In practice, the actual information system does not allow distinguishing between *regular* sales (delivered from inventory) and *custom* sales (delivered when the corresponding order from supplier arrives). Hence, statistics from previous months sales totalize sales from both order types in a single figure. These statistics are then used to determine the value for *Desired UMG inventory*. *Desired UMG inventory* acts as the goal of the inventory adjustment loop (B1).

Which are the consequences of this situation? The author hypothesized that the goal of loop B1 should be determined only by the deliveries (sales) from the inventory controlled by loop B1, in this case, *UMG regular sales*. If deliveries (sales) from other inventories not under control of loop B1 are added to the determination of the goal of loop B1, then the goal will have a value higher than required, and the inventory will be adjusted to a level higher than what is needed, potentially explaining why levels of inventory are higher than desired.

7.4.2.2 Inventory from CO is used in the stock ordering policy

As the parts corresponding to custom orders arrive to UMG, the parts accumulate in the same warehouses than the parts that pertain to the inventory for regular sales. When Head Office and branches register in the system the inventory transactions, there is no distinction between the parts already allocated to a custom order and the parts accumulated in inventory. Hence, the system registers the parts accumulation as a single quantity of inventory.

Inventory information is downloaded from the central system periodically in order to calculate the stock orders for the next month. To what extent does such information distort the stock ordering decision? Parts arriving from custom orders and pending to be delivered to customers may cause the person responsible for the stock ordering calculation to perceive that there is more inventory than what actually exists.

The author hypothesized that taking into account the total inventory, that is including the parts accumulated from custom orders, as input for the stock ordering policy may lead to an incorrect perception of the actual inventory in the loop B1. Inventory available for regular sales may be perceived as high not because it is high, but because of the accumulation of custom orders pending to be delivered (in *Inventory from CO)*. If the information used to make a decision is distorted, the ordering decision will be distorted as well. Such distortion can potentially explain instability in orders.

In order to test these two hypotheses, the author developed a simulation model corresponding to the causal structure in Figure 28.

7.4.3 Model boundary for the second iteration

The boundary of the model to be built during the second iteration represents an expansion of the boundary created in the first iteration (Table 1). The new boundary is summarized in the boundary chart of Table 3.

Endogenous	**Exogenous**	**Excluded**
Stock orders	Regular orders	Uncertainty in order lead-time
Custom sales	Custom orders	Manufacturers production and delivery policies
		Finance sector
		Emergency orders and sales
		Any effect of UMG's delivery delay or other variables on demand

Table 3. Boundary chart for the model of the second iteration

As in the first iteration, UMG's stock orders to the manufacturer will be captured endogenously. The reason is that stock ordering is the only type of order under direct control of UMG (the other two are directly triggered by customers); hence, the determination of the stock ordering quantity appears both as a potential cause for high inventory and a potential leverage point regarding inventory control.

The model is then driven by exogenous time-series representing different patterns of custom and regular orders. The addition of these exogenous variables is supported by the causal hypotheses to be tested in the second iteration, which attempt to explore the effect of *custom* sales in the *stock* ordering process[9].

All uncertainties in ordering lead-time are again excluded, as well as any possible effect from delays in production or delivery from manufacturers. Finally, any effect of UMG's financial capability on the supply from manufacturers is also excluded.

The causal structure in Figure 28 have been modified in order to portray the boundary of the simulation model (Figure 29):

[9] *Emergency* orders and *Emergency* sales, although also may have an effect on the ordering process, are not included for simplicity and because of their low volume in operations compared to regular and custom orders.

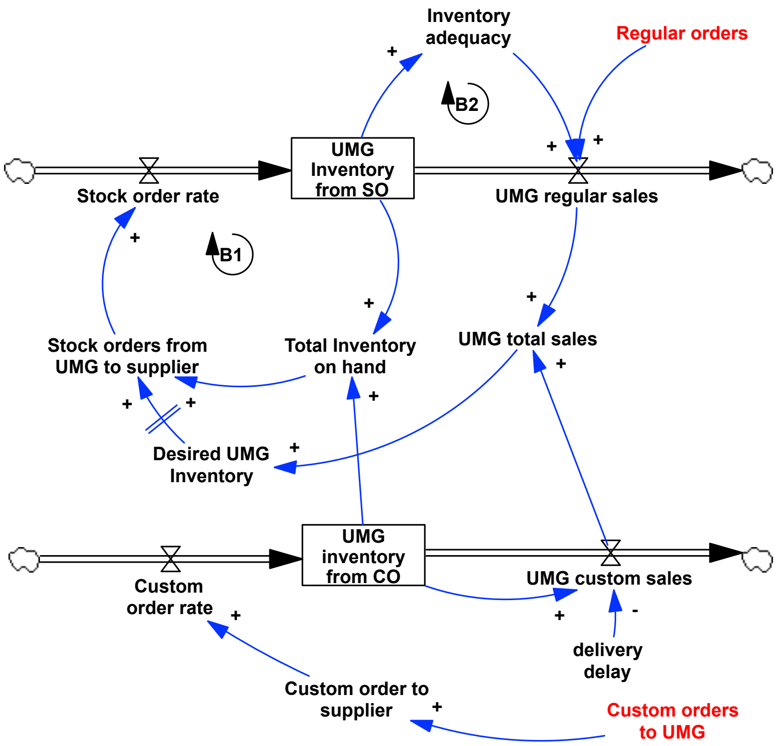

Figure 29. Overview of the causal structure to be simulated in the second iteration

It can be seen how the structure related to loops B3 and B4 in Figure 28 is not included in the boundary because orders (regardless the type) from customers are treated exogenously. Making custom orders endogenous would require the inclusion in the model of the dynamics of inventory and orders at the customer side. Although such an inclusion could bring insights into the purchasing behavior of the customers and their effect on UMG's inventory behavior, the author decided not to include them unless more evidence could show the necessity to do so.

The variable *Total inventory on hand* is the sum of both inventories and have been added for clarity. Finally, Figure 29 shows in red the two exogenous variables to be used as the possible combinations for scenario testing in the simulation runs.

7.5 UMG's supply chain physical structure

In order to capture more realistically the behavior of the supply chain under the new dynamic hypothesis and include new relevant variables elicited during the second GMB session, the model structure was refined accordingly. Such a refinement began with the specification of the physical flows across the supply chain. This section presents a general description of the material flows, the dynamics of lost sales, and estimation of two relevant parameters: lead-time and order fulfillment from supplier.

7.5.1 General description

The material flow followed by the orders and spare parts was elicited during the second GMB session. The physical process an order follows from the moment the order quantity is determined (ordering decision) until the parts arrive at UMG was defined in these sequential steps:

1. Approval from management and applying for import license (1 month)
2. Arranging packing of spare parts at the supplier side (21 days)
3. Booking the container (1 week)
4. Shipment to Myanmar (1 week)
5. Shipment at the port (1 week)
6. Customs clearance (1.5 months)

Although all these steps are important for the process being modeled, an effort was made to aggregate them in order to make the model as simple as possible and to avoid the need of collecting more numerical data than what possibly exists.

Figure 30 shows the aggregated picture of the material flow of orders and spare parts in the supply chain.

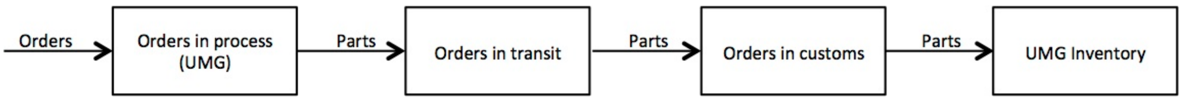

Figure 30. Material flows in the spare parts supply chain

The flow starts inside UMG with the new orders placed by the inventory management section. Orders defined in spreadsheet files are processed through different levels of approval at UMG. Discussions with the company's management revealed that spare parts have the highest priority in the monthly financial allocations (the main reason for approval is financial capability to pay to suppliers). Group participants described that although the approval process takes time, the rate of approval is high enough to consider the non-approval rate negligible. Thus the approval decision was discarded as a source of important dynamics in the model and was not included. In other words, it was assumed that UMG's management approved all the spare parts ordered.

After approved, orders reach the logistics department, where import license, packing arrangements and container booking are done. In total, the process of approval and logistics was aggregated in a single step called *Orders in process* (Steps 1, 2 and 3). Although an additional disaggregation could have been done by differentiating between the steps mentioned, the author found no need to do so: all three steps are sequential and according to UMG officers, each step often takes the expected amount of time, with rare exceptions.

Thus, a single stage of orders in process at UMG appeared adequate enough for the purpose of the model.

Once the order is processed at UMG and placed to the supplier, the supplier makes the arrangements and delivers the shipment of the parts. The shipment is delivered mostly by sea shipping. Once the parts arrive to Myanmar, arrangements are made in the port, before they finally start the customs clearance process. These two steps have been enclosed in a single stage called *Orders in transit (Steps 4 and 5)*. The reasons why this stage was considered separate from *Orders in process* are: (a) the conceptual unit changes from orders in terms of information to actual spare parts, and (b) it is recognized itself by the participants as inventory in transit, so keeping it as a separate stage allowed direct correspondence between the group's mental model and the simulation model.

Once the spare parts arrive to Myanmar (usually shipped from Thailand or Singapore), the parts pass through the customs clearance process. The time to complete such clearance has presented instability in the past. Hence, unlike all the previous stages, the time for this stage represents a potential source of uncertainty, reason why *Orders in customs* was considered explicitly as a different stage from the *Parts in transit* although conceptually the parts are still in transit to UMG. Finally the parts arrive to UMG's inventory after the custom clearance process finishes.

7.5.2 Lost sales

In the case of stock orders, when a customer places an order, the customer waits for the order to be delivered at a certain time. If after that time the order has not been delivered, the customer cancels the order, generating a lost sale. Once a stock order has been placed, customers are willing to wait up to one week before they cancel the order. In cases where only UMG can provide a particular spare part, the customer then is pushed to make a custom or an emergency order.

7.5.3 Lead-time estimations

In order to crosscheck the lead-time values provided by the participants, numerical data was collected. Although, no data exists regarding the actual duration of each separate phase, the aggregated lead-time is registered in the information system, from the moment the order quantity is determined to the moment the order arrives to UMG's inventory. Figure 31 shows the lead-time for sea shipments (corresponding to *regular* and *custom* orders) and air shipments (corresponding to *emergency* orders).

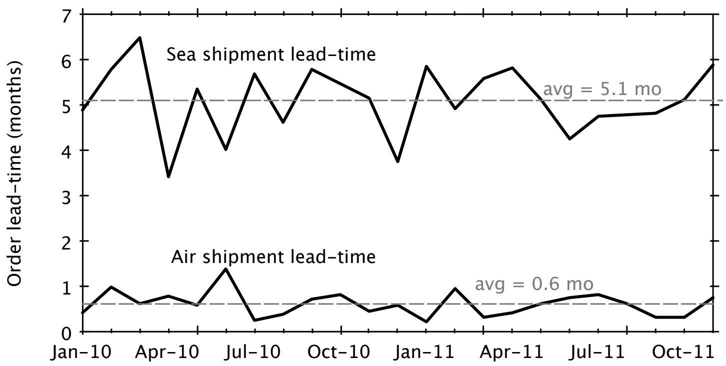

Figure 31. Aggregate lead-time for air and sea shipments

Data reveals that both sea and air shipment lead-times vary over time around an average of 5.1 months and 0.6 months for sea and air shipments correspondingly.

It can be noted that the average for sea shipments extracted from numerical data is different of the average given by the participants (4 months). Such difference was presented to participants directly involved in the logistic process. The conclusion was that the system might show extended lead-times due to delays in the data input process not directly linked to the supply chain operation. Hence, it was decided that the average (lower) values provided by the participants during the session would be used in the model. However, lead-time variability emerged as a potential variable to consider for future test scenarios in the simulation model.

7.5.4 Orders placed by UMG vs. orders fulfilled by the supplier

An additional point that needed consideration was the fulfillment ratio of the supplier to UMG. Are all orders placed by UMG to the supplier fulfilled? Table 4 shows a comparison of the orders placed to the suppliers per month, the parts received from the corresponding orders and a percentage of parts ordered vs. received. Several months show 100% fulfillment, with only one month (Jun-11) below 90%. In average 98% of the orders placed to the supplier are received, being the other 2% orders that were not fulfilled. Given these facts, the fulfillment was assumed to be 100%, meaning that all parts ordered are actually received.

	Orders to supplier	Parts received	Ordered/Received
Jan-10	19496	19487	100%
Feb-10	19516	19516	100%
Mar-10	11463	11334	99%
Apr-10	5719	5681	99%
May-10	14816	14806	100%
Jun-10	5824	5821	100%
Jul-10	13631	13630	100%
Aug-10	2281	2330	102%
Sep-10	2348	2201	94%

Oct-10	25459	24943	98%
Nov-10	15552	15543	100%
Dec-10	8598	8584	100%
Jan-11	9783	9900	101%
Feb-11	8431	8424	100%
Mar-11	15549	15435	99%
Apr-11	1420	1415	100%
May-11	34104	33651	99%
Jun-11	10119	6809	67%
Jul-11	6293	6251	99%
Aug-11	7352	7100	97%
Sep-11	1327	1327	100%
Oct-11	381	381	100%
Nov-11	416	416	100%
Dec-11	506	505	100%

Table 4. Orders placed to supplier vs. orders received

7.5.5 Stock and flow for regular orders

7.5.5.1 General description

The physical path followed by the regular orders placed by customers and the stock orders placed by UMG to the supplier are presented in Figure 32:

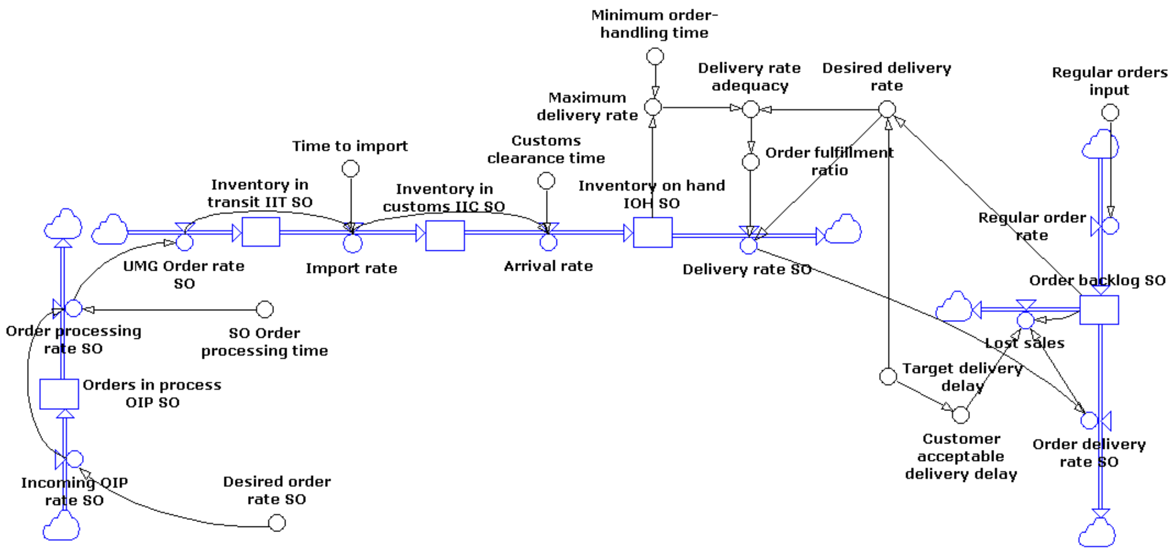

Figure 32. Physical flow of the stock orders

The desired quantity to order for stock orders (SO) in calculated in *Desired order rate SO* as defined in 5.4.3 (the sum of the adjustments for inventory in transit, inventory on hand, safety stock and order backlog). The order is placed and becomes an *Order in process OIP SO*. Orders are in process for a time defined in *SO Order processing time* and then as the supplier ships the spare parts, the parts become *Inventory in transit IIT SO*. After a *Time to import*, the parts arrive to customs and become *Inventory in customs IIC*

SO. Once cleared from customs, the parts are delivered to UMG's *Inventory on hand IOH SO* from which the sales are delivered to the final customer.

7.5.5.2 Lost sales

The regular orders made by the customer are represented by the exogenous variable *Regular orders input*. Such orders enter the *Order backlog SO* as customers place new regular orders. Orders are depleted from the backlog as deliveries are made from stock in *Delivery rate SO*. However, orders not delivered in the maximum time the customer expects (*Target delivery delay*) are cancelled, depleting the backlog. Such cancellation does not occur instantaneously: Some customers are willing –or have- to wait longer, other customers cancel immediately. Hence, orders cancelled (called *Lost sales* at UMG) are formulated as follows:

$$Customer\ acceptable\ delivery\ delay = Target\ delivery\ delay * 1.2$$

$$Lost\ sales = MAX\left(\frac{Order\ backlog\ SO}{Customer\ acceptable\ delivery\ delay} - Order\ delivery\ rate\ SO, 0\right)$$

According to these formulations, customers are willing to wait up to 20% more of the time UMG set itself for the *Target delivery delay*. Such waiting time is represented by the *Customer acceptable delivery delay*. *Lost sales* occur when the *Order delivery rate* is lower than the delivery rate acceptable by the customers, which is *Order backlog SO/Customer acceptable delivery delay.* In other words, lost sales are defined by the difference between the rate customers expect the parts to be delivered and the rate the parts are being actually delivered.

7.5.5.3 Material delays

Three material delays exist in the physical flow described: *Order processing rate, Import rate* and *Arrival rate*. In order to model the material delays accordingly to the behavior of the system, a study was done comparing the orders placed and the order arrival per month Figure 33 shows in the orders placed (solid line) and orders received (dashed line). Both lines present a lag of about 5 months, coinciding with the lead-time estimations made in 7.5.3. However, the peaks in the orders received often do not equal in amplitude the peaks in the orders placed, which leads to think that orders arrive dispersed in a span of time higher than one month.

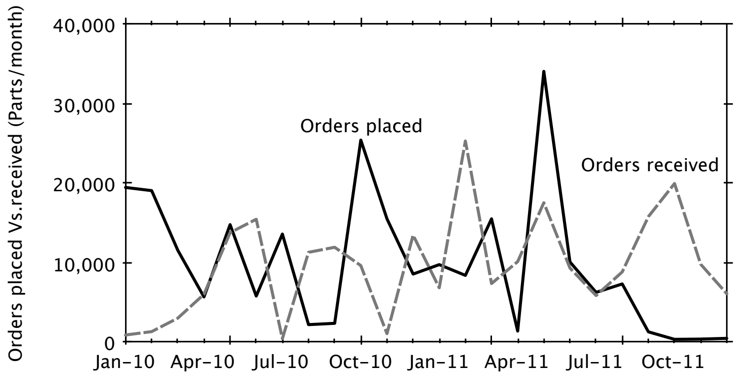

Figure 33. Orders placed vs. orders received over time

With the goal of clarifying the behavior of the material delays a sample of individual monthly stock orders was compared with the corresponding arrivals. Figure 34 shows individual orders as colored dots and the reception of such orders as solid lines. Each order and its reception is associated by a different color.

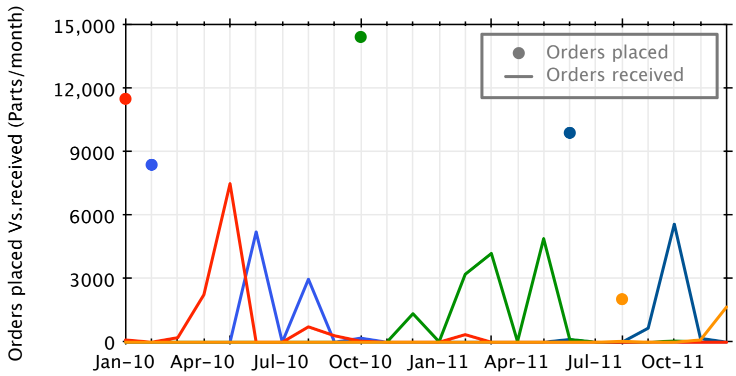

Figure 34. Orders placed vs. orders received for selected months

Figure 34 shows important characteristics in the relation between the orders and the arrival of parts:

1. Each order placed arrives in a span of 3-6 months.
2. In general it takes 2-3 months for the first parts to arrive after an order is made.
3. Once orders start arriving, arrivals quickly reach a peak (except for the order made in Oct-10) and then deplete.

Characteristic 1 suggests that although participants provided fixed lead-times as estimates of the delays, in reality the process does not resemble a pipeline delay where the all the parts arrive at the same time after a fixed delay. Characteristics 2 and 3 suggest that the material delay is however a high-order delay. Once the order is placed, parts start arriving one or two months later. Hence, the three material delays were modeled as high order delays[10]. The time of the delay was set equal to the estimates provided by the participants.

[10] Tests would later reveal that a 6^{th} order delay was a good approximation

7.5.6 Stock and flow for custom orders

Custom orders (CO) share the same physical flow of *Regular* orders. However, the hypotheses to be tested imply dividing the supply chain for each type of order. I analyzed the following points in order to assess the validity such a division:

- Parts ordered for *custom* orders usually are not physically mixed with parts ordered for *regular* orders.
- Some customers cancel *custom* orders. In that event, the parts that have already arrived to UMG's inventory become part of the regular stock. However, such cancellation rate was described as small enough to be negligible in the model.
- Customers wait for the custom order to arrive rather than asking for preliminary partial deliveries from stock to be compensated later. The main reason for this behavior is that custom orders offer lower prices to customers, which are not interchangeable with parts delivered from regular stock.

Given that the previous conditions hold true, I made the assumption that parts from both order types do not mix in the average case. Hence, I developed a separate stock and flow structure for *custom* orders as depicted in Figure 35. Since the physical flow is the same of the stock orders, the material delays and lead-times were modeled similarly.

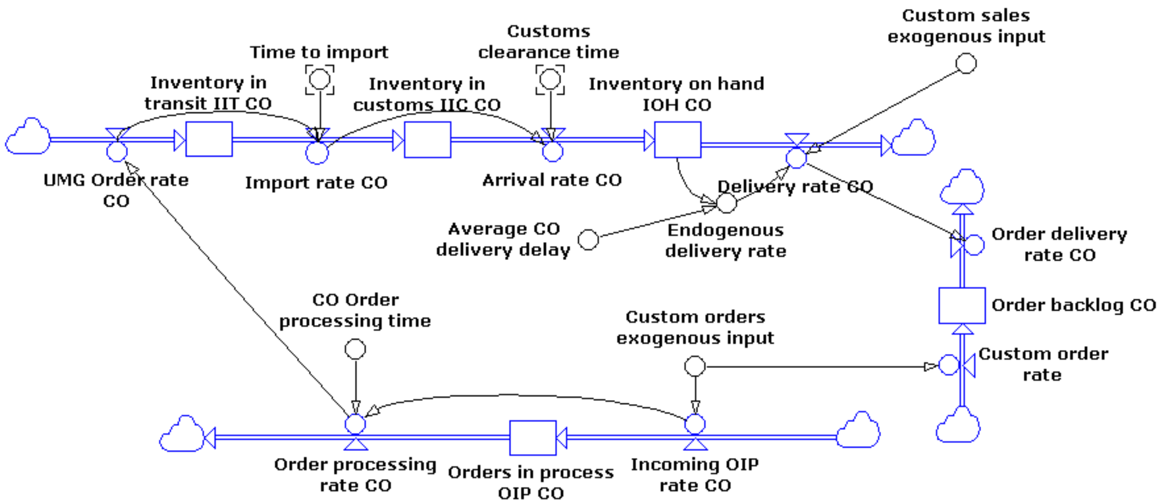

Figure 35. Physical flow of the custom orders

The physical structure of the *custom* orders resembles that of the *stock* orders. Orders made by customers enter an order backlog and start the ordering process to supplier. The custom order is raised to the supplier (*UMG Order rate CO*). The parts delivered by the supplier are in transit (*Inventory in customs IIC CO)* until the parts arrive to customs. Finally the parts arrive to the *Inventory on hand IOH CO*. IOH CO represents the temporal accumulation of spare parts created by the delay from the moment the parts arrive to the moment the parts are picked up.

Once the physical structure of the supply chain was defined, followed a closer study to the information flows influencing the stock ordering decision.

7.6 Information flows at UMG

Four types of information are used in the stock ordering process: (a) inventory in transit, (b) inventory on hand, (c) sales and, (d) seasonal forecasts. In order to build a model that better reflects how actual decisions are made, it was necessary to study the process followed to collect each type of information.

7.6.1 UMG's inventory in transit

When UMG has made an order to a supplier, officers are periodically monitoring the status of each order. Orders to suppliers are differentiated by order type. Hence, UMG's officers know which orders are intended to fulfill UMG's inventory (stock order), and which orders will be redirected to customers (custom and emergency order). This differentiation allows UMG to monitor the inventory in transit for stock orders accurately. Since the inventory in transit (IIT) is controlled locally at UMG Head Office, information is often available with a delay that spans from 1 to 5 days (the upper limit occurs when information from overseas is delayed). However, inventory in transit is monitored only once per month.

As mentioned in the first iteration, the manager takes into account only 50% of the IIT for the ordering calculations; hence the factor of reliability in inventory in transit presented in the first iteration is still included.

Given that the information for inventory in transit must pass through several stages before becoming available to the ordering process, the perceived inventory in transit (*Perceived IIT*) was modeled as a third-order information delay with a delay time of 1 month (*ttp IIT, time to perceive IIT*). The IIT is calculated from the three stocks that reflect the overall IIT (*Orders in process OIP SO*, *Inventory in transit IIT SO* and *Inventory in customs IIC SO*). Figure 36 shows the structure for the perception of the IIT:

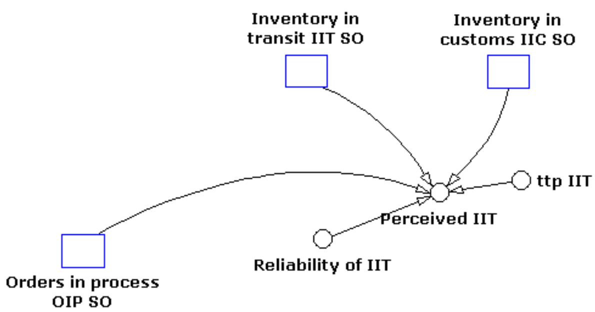

Figure 36. Stock and flow structure of the IIT perception

7.6.2 UMG's inventory on hand

Head Office and each of the branches across the country monitor the Inventory on Hand (IOH) weekly. The information is imported to the central information system at the Head Office once per month, from where it is downloaded periodically as an input to the ordering decision. Such process is done gradually; information from each branch is acquired at distinct days every month. In general, trustable information about inventory becomes available after 1.5 months.

The perception of the inventory on hand was modeled as a third order information delay for the same reasons given for the inventory in transit as depicted in Figure 37:

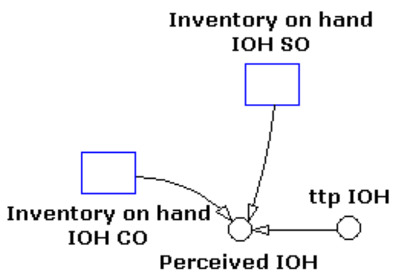

Figure 37. Stock and flow structure of the IOH perception

7.6.3 Sales

The source for sales information is deliveries to customers. Deliveries are made from inventory in the case of regular sales or from custom sales. As it was mentioned before, regular and custom sales are summed to make the total sales. Hence the model includes a variable called *Total sales* composed of the sum of the delivery rate from regular sales (*Delivery rate SO)* and the delivery rate from custom sales (*Delivery rate CO*) as portrayed in Figure 38.

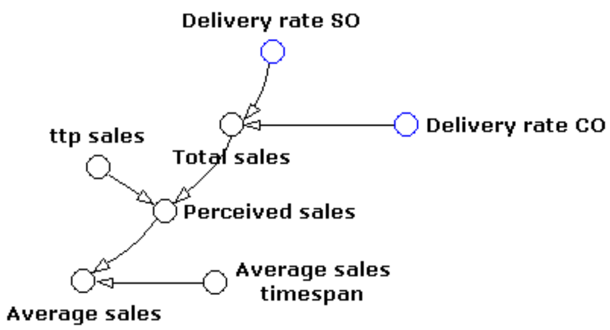

Figure 38. Stock and flow structure of the perception of sales and averaging

Every branch stores original sales statistics in spreadsheet files and sends periodically the information to the Head Office. However not all branches send the information at the same time, and it has been reported that some branches take longer than others or send incomplete information.

Once the information is received at the Head Office, it is processed and imported into the central system in a monthly basis. Information from the central system is then used for the ordering decision.

In conclusion: (a) there is a delay of about 1 week in the sales information from the moment the sale occur to the moment it is registered by the branch, (b) another delay is added of about 1 month between the moment the information is registered in the branch until it is imported in the central system, and (c) the process of transmission of the information from the branch to the central system added distortion to the data during several months in the past two years. After the information of sales is collected for the ordering decision, sales from the last six months are averaged. In order to account for these effects, two variables have been added, a third-order information delay that accounts for the reporting delay as information moves through several stages before reaching the decision point (*Perceived sales* in Figure 38), and a first-order information delay of six months (*Average sales timespan* in Figure 38) that accounts for the 6-month average made to estimate the expected sales.

7.7 Simulation model

The complete stock and flow diagram presented in Figure 39 corresponds to the integration of the components presented in the previous section. In summary, it portrays the supply chain and the ordering policy for stock orders (upper part of the diagram) and the supply chain involved in the custom orders (bottom part of the diagram). The *Inventory on hand CO* (inventory accumulated from custom orders not delivered yet) and the *Delivery rate CO* (delivery or sales of custom orders to customers) are the variables that link both supply chains (filled with blue in the diagram). The inventory on hand from custom orders adds to the total *Perceived IOH*. The delivery rate of custom orders, or custom sales, adds to the *Total sales*. Both variables are used for the stock ordering policy. The simulation will allow testing the influence of the custom orders operations in the behavior of the stock orders.

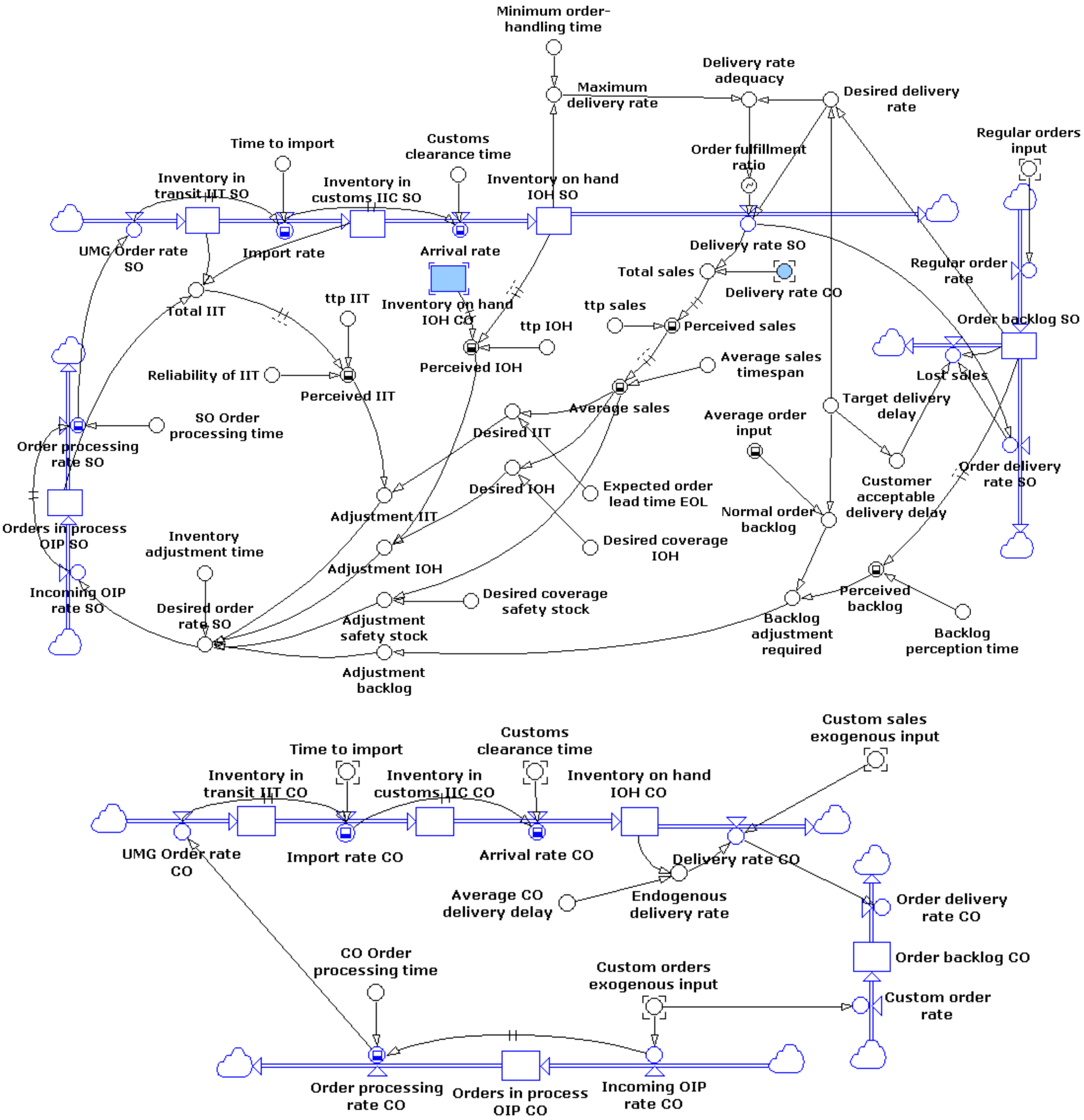

Figure 39. Complete stock and flow structure for the simulation model of the second iteration

7.7.1 Parameter values

During the second session, a refinement was made on the physical supply chain requiring estimates for the new material delays introduced. The participants provided the following average values for such delays:

Model parameter	Value
Backlog perception time	2 months
Target delivery delay	0.125 months (0.5 week)
Sales perception time (ttp sales)	3 months
Average sales timespan	6 months
IOH perception time (ttp IOH)	2 months
IIT perception time (ttp IIT)	1 month
Expected order lead-time EOL	4 months
Desired inventory coverage	1 month

Desired coverage safety stock	1 month
Reliability of IIT	50%
Inventory adjustment time	1 month
SO Order processing time	2 months
Time to import	0.5 months
Customs clearance time	1.5 months
CO Order processing time	2 months
Average CO delivery delay	0.5 months (2 weeks)
Customer acceptable delivery delay	0.15 months (0.6 week)

Table 5. Parameter values for the second iteration

7.8 Model validation

One of the aims of the second iteration was to make the model resemble in more detail the actual workings of the spare parts supply chain. Hence, during the validation phase, emphasis is given to the partial reproduction of historical behavior of key supply chain variables.

7.8.1 Partial model validation of the physical flow

Partial model tests allow testing subsections of a model by replacing endogenous inputs with historical time series (Homer, 1983). If the output of the subsection deviates significantly from the historical output then formulation or parametric errors should exist. The partial tests that follow attempt to validate the structure of the physical flow of the stock orders supply chain as presented in Figure 32. It must be noted that such a test cuts the feedback structure involved in the ordering process.

7.8.1.1 Single order inputs

Single stock order inputs (pulse inputs) were applied to the stock order supply chain for four different months. Each order flows through the supply chain until it reaches the inventory on hand. The simulated output of the reception of orders at inventory on hand is then compared to the historical records for order reception. The results are presented in Figure 40. Each dot represents an order placed. The solid lines represent the corresponding reception rate per month for each order. The dotted lines represent the corresponding simulation output for the reception rate.

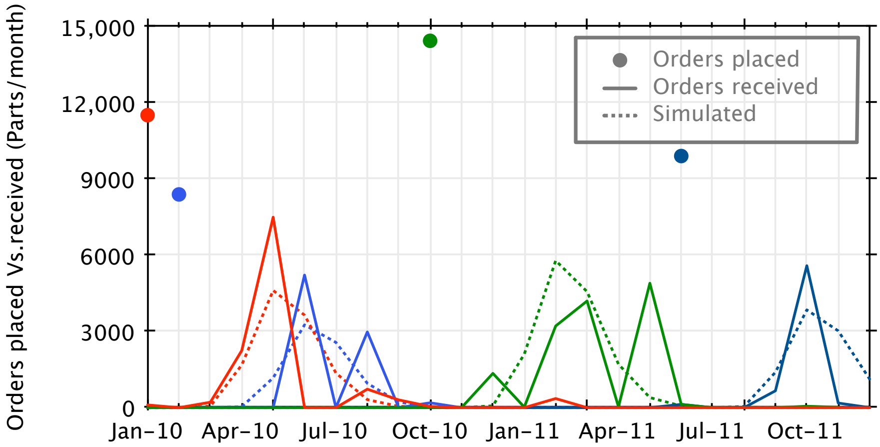

Figure 40. Comparison of historical data and simulation output for reception of stock orders

In the figure can be observed that the order made in Jan-10 (red dot) arrived in a span of three months, whereas simulation output spans through 5 months. However, for the orders made in Oct-10 (green dot), the orders were received in a span of 7 months, while the simulation output spans through 5 months. Differences can also be detected in the peaks between the historical and simulated output. This shows that the rate at which parts were distributed through the supply chain changed over time, which is in agreement with the variable lead-times shown in Figure 31. Also, some orders arrived less dispersed in time than others. However, participants did not reveal any major change in the supply chain during the period covered by the historical data. Thus, the approach taken was to choose a delay order that could serve approximately well in the average, although deviating from individual cases.

A key determinant of the shape of the output of a material delay is the order of the delay. Hence, the test focused on calibrating the model with different delay orders. Dotted lines show the simulation results using 6^{th} order material delays and constant values for each delay time.

7.8.1.2 Historical orders

A second test used as input total monthly historical orders and total monthly historical sales, and compared the simulation output of total inventory on hand with the historical inventory on hand. For this test, the author added an auxiliary structure including emergency orders in order to get comprehensive total values. Figure 41 shows the results:

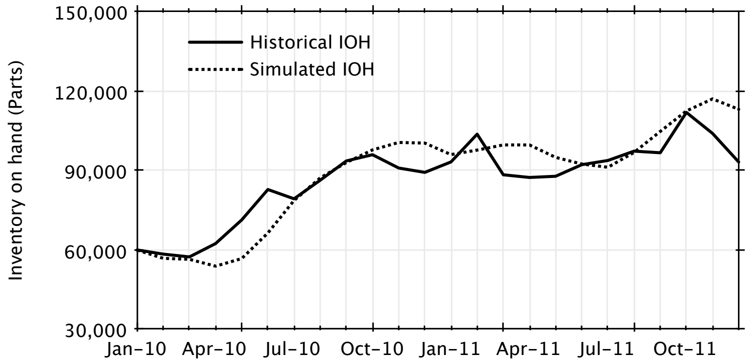

Figure 41. Historical vs. simulated output of the total inventory on hand

Figure 41 shows the historical inventory on hand (bold line) and the simulation output (dotted line). Both results present a growing pattern of behavior although they do not match point to point values. The result was considered acceptable given that:

- The purpose of the model is not to estimate a detailed quantity of spare parts to order but to study general patterns of growth and instability.
- The model aggregates several types of spare parts of different nature into a single supply chain.
- The historical data used as input in the simulation model was obtained from the central information system at UMG. It was revealed already how the data may have potential inconsistencies that distort the information. Hence, the historical behavior to match with may prove to be not totally accurate against the real systems' history.

Once the tests provided confidence on the physical structure of the supply chain, the next stage was to analyze the behavior of the model under different scenarios.

7.9 Analysis of model behavior

In order to understand the behavior of the model structure, the model was exposed to different scenarios for the exogenous variables defined: *Regular sales* and *Custom orders* (See Figure 29)

7.9.1.1 Scenario 1: Zero custom orders with constant regular sales

The configuration of this scenario is summarized as follows:

Exogenous variable	Value
Regular sales	Constant
Custom orders	Zero

To start the analysis, custom orders are set to zero. Regular sales are set constant. Custom sales are endogenous, based on a simple first order outflow of the *Inventory on* *hand IOH CO*, meaning that as the parts arrive, the customers pick them up with an average delay of two weeks. The behavior of key variables is portrayed in Figure 42:

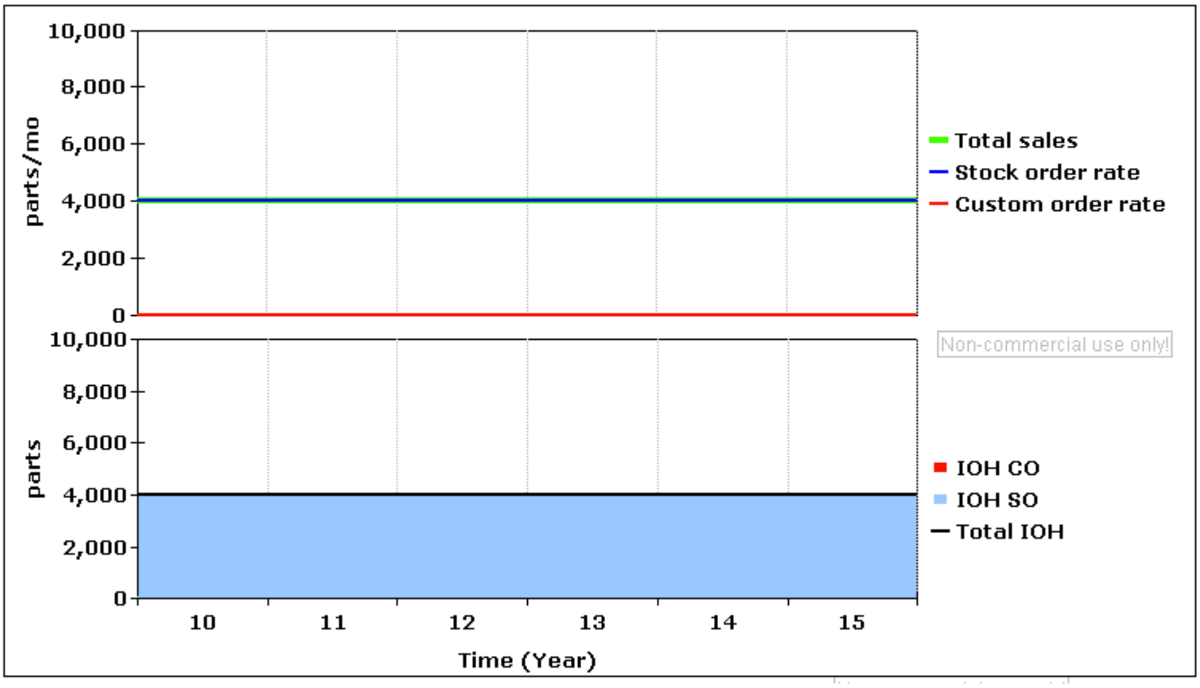

Figure 42. Simulation output for scenario 1

The graph in the upper part of Figure 42 shows the main rates involved: Total sales, that is the sum of regular and custom sales (green line), the stock order rate (blue line) and the custom order rate (red line). Given that the scenario is defined for zero custom orders, there are also zero custom sales. Hence, total sales equal regular sales and the stock order rate equals total sales. The inflow is equal to the outflow and the system is in equilibrium.

The graph in the lower part of Figure 42 shows the total inventory on hand (Total IOH, black line) and the two stocks that make up the Total IOH, that is, the inventory on hand from stock orders (IOH SO, blue fill) and the inventory on hand from customer orders (IOH CO, red fill). Since total inflows (order rate) equals total outflows (total sales), the system remains in equilibrium and total inventory on hand (Total IOH) remains constant at 4000 parts. Furthermore, the total inventory on hand is composed only of the inventory accumulated from stock orders. No custom orders imply no inventory is created from the parts waiting to be delivered to customers. In general this simulation run reflects the same equilibrium behavior presented in the equilibrium case of the first iteration in 5.6.1.1.

7.9.1.2 Scenario 2: Pulse custom orders with constant regular sales

A common pattern for custom orders is the equivalent to a pulse function. When a particular spare part has a malfunction in a machine, and the spare part is not available at UMG's stock, customers place custom orders to UMG to import the spare parts directly from the supplier. A customer with an installed base of dozens of machines can place voluminous custom orders to cover inventory for extended periods of time. However, those orders are not permanent, often such orders are placed once per year or even once in a lifetime. The pulse pattern reflects the sporadic nature of custom orders. The scenario is then defined as follows:

Exogenous variable	**Value**
Regular sales	Constant
Custom orders	Pulse

The simulation output is presented in Figure 43:

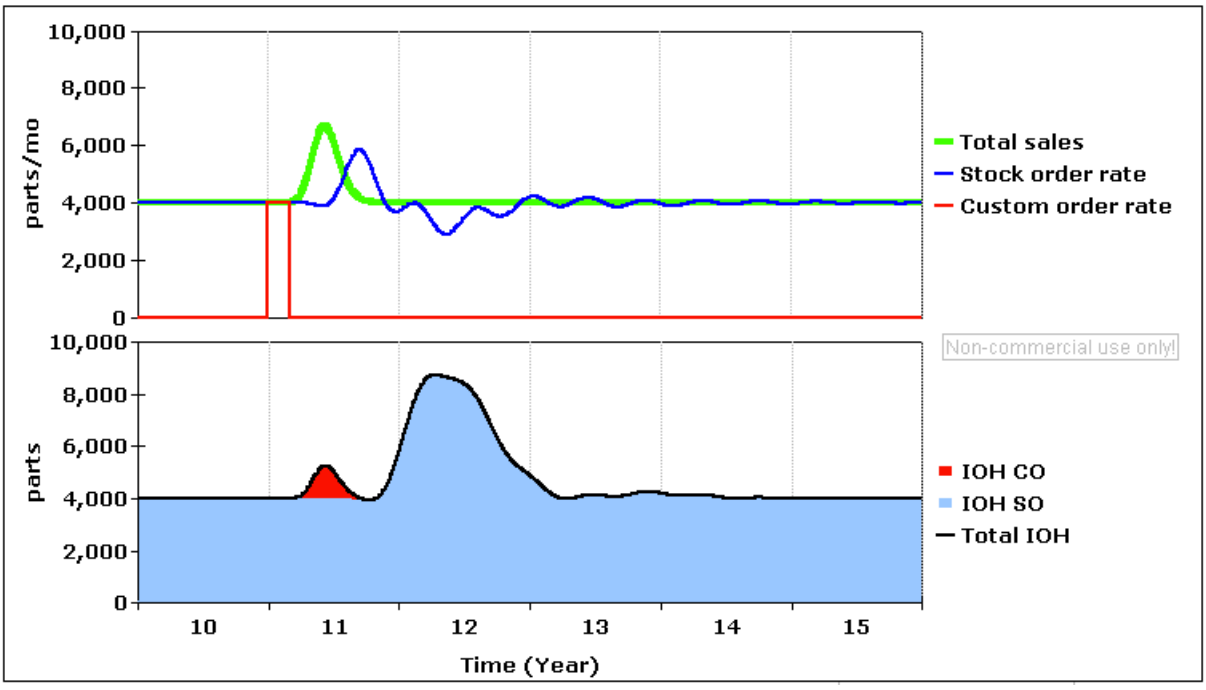

Figure 43. Simulation output for scenario 2

The pulse introduced in the *Custom order rate* increases the custom orders to 4000 parts per month during one month (red pulse at start of year 11). The new order made is received by UMG around 4 months later (not shown). As the order is received, the parts are delivered to the customer, increasing *Total sales*. Higher *Total sales* drive a higher desired inventory, increasing the *Stock order rate* above its equilibrium level of 4000 parts/month, up to 5700 parts/month (blue line second half year 11). However the increase in sales is temporal. Custom sales decrease to zero as parts are delivered, bringing *Total sales* back to the original equilibrium value (second half year 11). As sales decrease, the *Stock order rate* diminishes to compensate for the extra inventory, and briefly oscillates around the previous equilibrium value of 4000 parts/month (first half year 12). The *Total IOH* increases as the parts for the custom order arrive and decreases back to the equilibrium value as the parts are delivered (red fill at half of year 11).

So far the system appears to be self-regulated and back to its original equilibrium. However, the adjustment left important traces in the *Total IOH*, which increased from 4000 parts to 8700 parts (first half year 12). During the remaining of year 12, the inventory gradually decreases as orders decrease below the rate of sales, reaching the original equilibrium value at the first half of year 13. The delays between the original action and its consequences are relevant:

- The Total IOH reaches its peak (half year 12) more than one year after the original custom order was placed (beginning year 11) and approx. one year after the peak in sales (half year 11).
- The inventory reaches equilibrium (beginning year 13) two years after the custom order was placed (beginning year 11).

It is important to note that during the whole simulation, the regular sales have remained constant.

This scenario shows that the consequences of using the total sales rate (custom + regular sales) in the stock ordering process are important in magnitude and far reaching in time: A customer order placed today can cause an amplification of more than 100% in inventory. Furthermore, the amplification occurs one year and a half later, long after the last part of the original order have been delivered to the customer.

Failure to link cause and effect when both are distant in time has been documented as one of the barriers for learning in complex systems (Sterman, 1994). It is no surprise that UMG does not distinguish among the sales from different types of orders when forming sales expectations: The consequences of not doing it are only visible far ahead in time and are difficult to link with the original cause.

7.9.1.3 Scenario 3: Pulse custom orders with sinusoidal regular sales

Scenario 2 has an important simplification: Regular sales in reality are far from constant. Figure 44 shows the historical regular sales for the most representative branch. The graph shows how sales fluctuated. Hence, it is more realistic to use similar fluctuations for the regular sales.

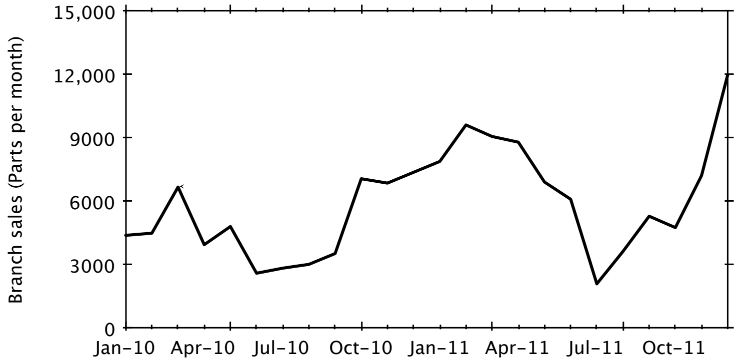

Figure 44. Historical branch regular sales

Thus, scenario 3 tests the influence of a pulse on custom orders on a system with oscillating regular sales. In this case, the base behavior of the supply chain will be oscillatory with a period of 1 year, which is similar to that observed in the historical sales data. The scenario will test the effect of a pulse in custom sales on the regular fluctuations:

Exogenous variable	Value
Regular sales	Sinusoidal oscillations
Custom orders	Pulse

The results of the test are presented in Figure 45:

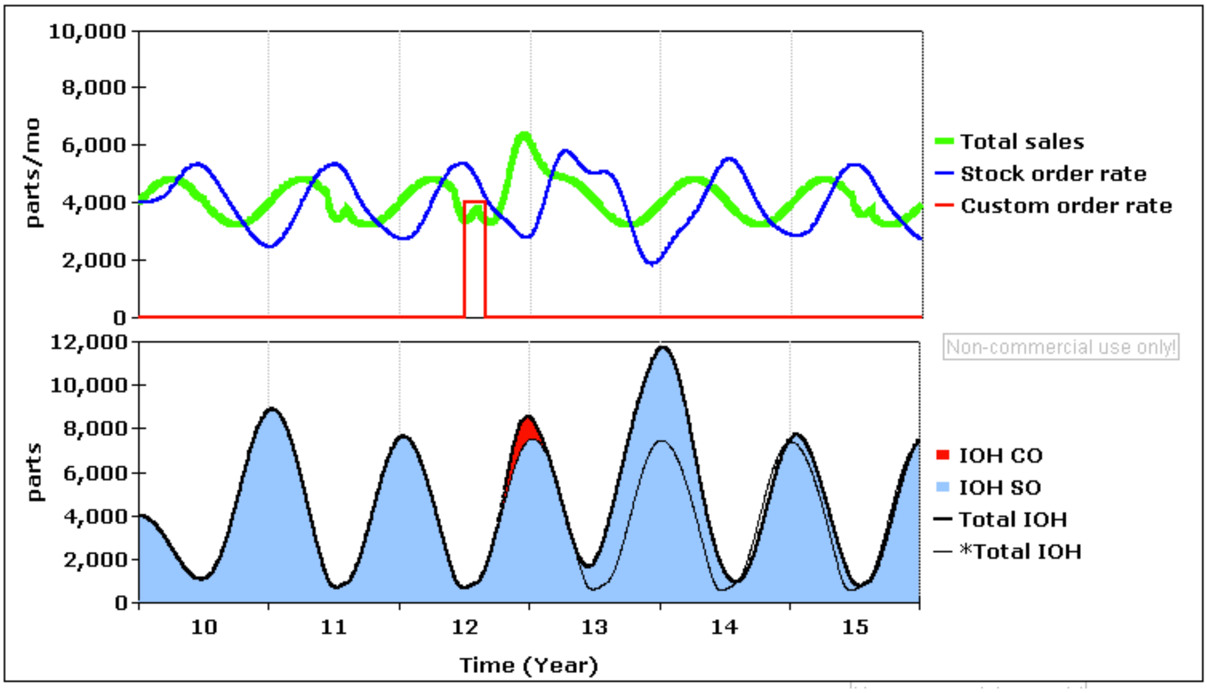

Figure 45. Simulation output for scenario 3

Before year 12 the system presents an oscillatory behavior with no influence of custom orders as that observed in 5.6.1.3. The pulse is introduced in the *Custom order rate* at the middle of year 12. As in scenario 2, the pulse is an increase in the custom orders of 4000 parts/month for one month. After the custom order is made and parts are received (not shown), the parts enter the inventory from custom orders (red fill at end of year 12) and

Total IOH increases. However such an increase is quickly cancelled as parts are delivered (beginning year 13). Custom sales cause *Total sales* to increase above normal levels (end of year 12). Such an increase in sales causes higher expectations of future sales, which increases the *Desired UMG inventory (*not shown*)*. A higher goal for inventory increases the *Stock order rate* above the base case values (compare mid of year 13 with mid of year 12). When stock orders arrive to inventory, the *Inventory on hand from stock orders IOH SO* increases also above normal levels, with an amplification close to 50% over the regular peaks (see comparison at the end of year 13 between Total IOH and the reference base run **Total IOH*). Thus, in an oscillatory pattern of stock orders, the response of the system to an input pulse in custom orders is amplification of the next fluctuation.

As in the previous scenario, delays play a key role in separating cause and effect: The amplification in the Total IOH occurs 1.5 years after the custom order was placed and one year after the original increase in *Total sales*.

In order to assess the possibility that such behavior have occurred at UMG, the author took a sample of spare parts with periodic volume of sales. From these spare parts, the author selected parts for which infrequent custom orders have been placed. Infrequent custom orders are assumed to resemble the effect of a pulse input.

Numerical data was collected for a group of the spare parts described. The data revealed that the situation depicted by scenario 3 have occurred at UMG. Figure 46 shows the behavior over time of key variables for a particular spare part: a *Cartridge*[11].

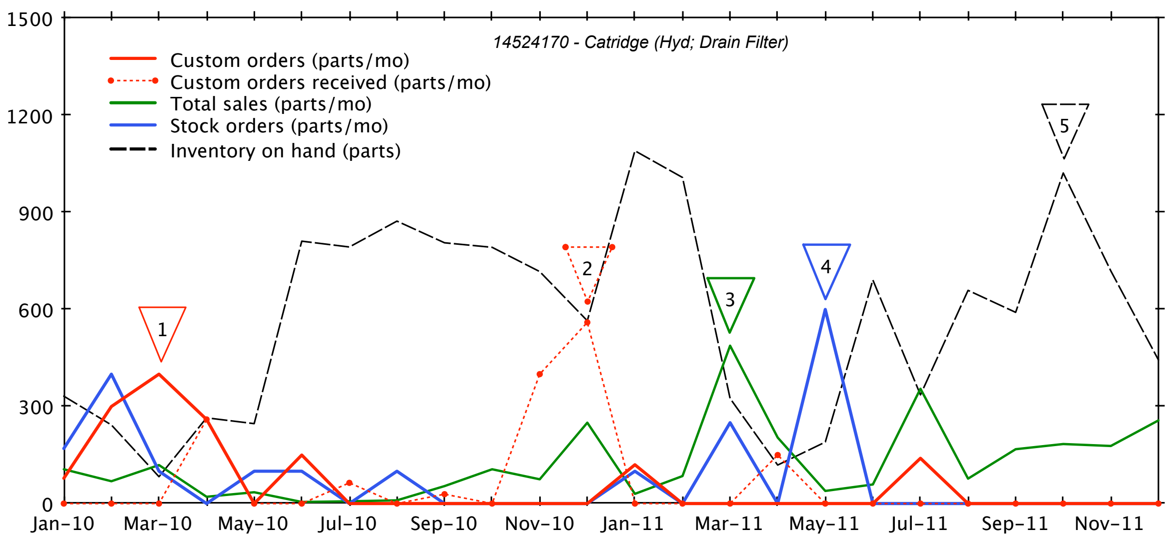

Figure 46. Historical behavior of a particular spare part with conditions similar to those of scenario 3

As an aid to understanding Figure 46, the author suggests to follow the sequence provided by the numbers on the graph:

[11] A cartridge used in the hydraulic systems of a popular model of excavators

1. Custom orders are placed (in similarity with the pulse input of the scenario under discussion).
2. After four months the parts arrive at UMG.
3. Two months after the parts arrived, parts are delivered to the customer, increasing the total sales rate.
4. Increasing sales augment sales expectations, which leads to higher stock orders.
5. As stock orders arrive (not depicted in the graph), inventory on hand increases.

Figure 46 shows how inventory raises due to high sales expectations based on wrong input (total sales rather than sales from stock). If the graph is compared to the simulation output of scenario 1, it can be seen that in both graphs the inventory on hand increases about 1.5 years after the order is made.

Is the increase in inventory necessarily undesirable? As in the simulation run of the second scenario (Figure 43), UMG reacts to the increased inventory by decreasing the stock orders, balancing the inventory back to the equilibrium level (loop B1 in Figure 29). By ordering less, sales can deplete the inventory until either it is too low and regular orders need to be made, or until a new sale from a customer order increases sales expectations over their normal value again. In summary, the extra-inventory is depleted by adjustments made in the regular ordering process. By constantly adapting to such changing conditions, it is understandable that UMG officers may have perceived a permanent inventory higher-than-desired as the norm rather than the exception.

Figure 47 shows the simulation output of a permanent condition of repeated pulses of custom orders and their effect on the system.

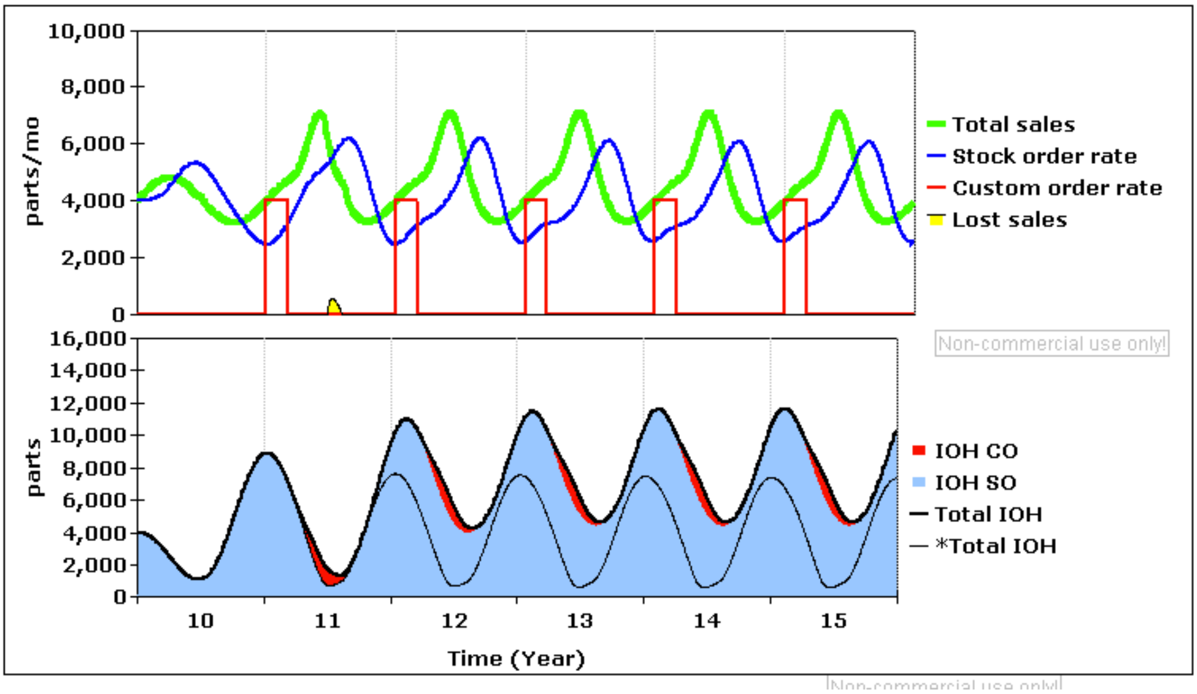

Figure 47. Simulation output for repeated pulses (scenario 3)

After the first pulse occurs at the beginning of year 11, the valleys and peaks of the remaining oscillations in inventory raise almost 4000 parts from the base case (see reference run *Total IOH) showing how frequent pulses of customer orders create a permanent condition of higher-than-required inventory levels, even if the regular sales have maintained the same pattern of behavior.

7.9.1.4 Scenario 4: Pulse in custom orders with zero regular sales

Scenarios 2 and 3 showed how the stock ordering policy allows the system to self-correct the high inventory levels in *Inventory from SO*. The key for the correction mechanism lies in the outflow of the stock of inventory: Regular sales. Once the parts ordered for the custom order are delivered, the extra remaining parts in *Inventory from SO* are delivered slowly from regular sales (second half of year 12 in Figure 43). What happens if that correction mechanism is distorted? A way to distort it is to set to zero the rate of regular sales. Once regular sales are zeroed, extra inventory cannot be corrected via this outflow.

To test the consequence of such condition, this scenario simulates a pulse input in custom orders with zero regular sales. Such is the case of a custom order for a spare part with low sales volume that is regularly not kept in stock by UMG. The scenario is summarized as follows:

Exogenous variable	Value
Regular sales	Zero
Custom orders	Pulse

The simulation output is presented in Figure 48:

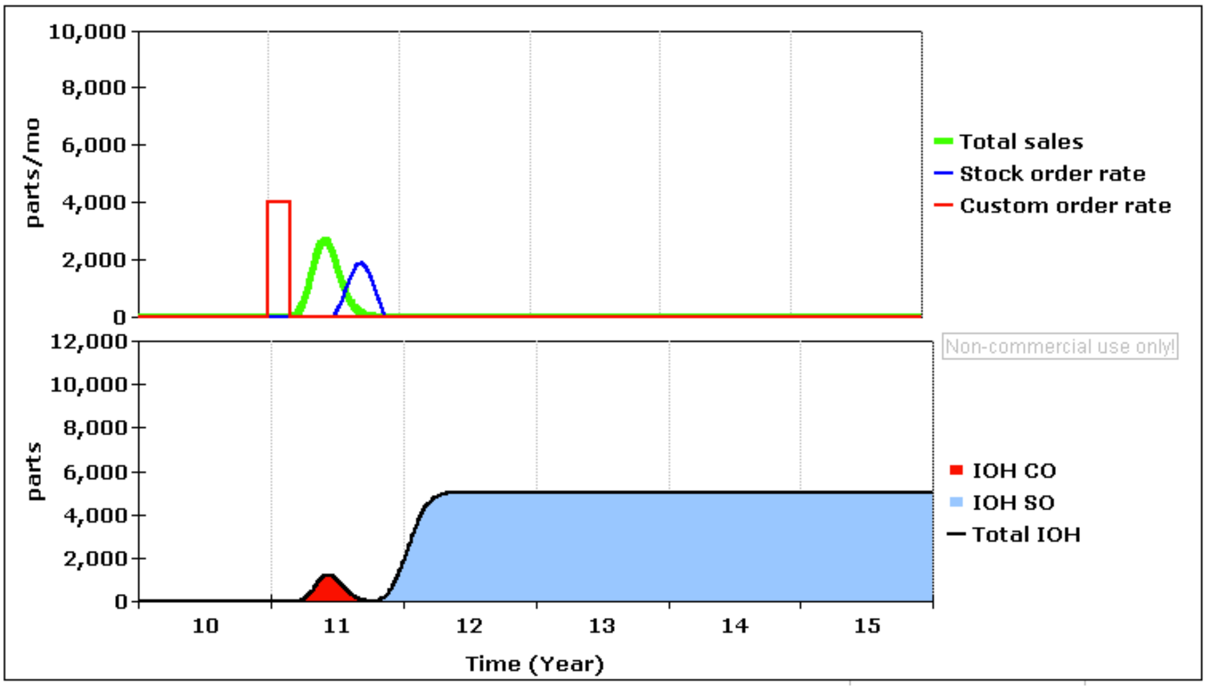

Figure 48. Simulation output for scenario 4

Initially all rates are zero. This situation implies that the spare part has no movement (sales or orders) in the supply chain. A custom order is placed at the beginning of year 11 (red pulse). As parts arrive (not shown) the *Total IOH* increases and decreases rapidly as parts from custom orders are delivered (red fill at mid year 11). Deliveries cause *Total sales* to increase (mid year 11). Such an increase leads to the misperception that the market is suddenly demanding the spare part[12], increasing the *Desired inventory* (not shown). As *Desired Inventory*, which is the goal of loop B1 (Figure 29) increases, stock orders increase (second half of year 11). As stock orders arrive, IOH SO grows (first half of year 12). However, the increase in sales is not permanent. In this scenario, there are no further regular sales. The IOH SO received from the stock orders remains untouched after several months (blue fill from second half of year 12 on).

In order to verify the existence of such case at UMG, numerical data was collected for spare parts satisfying the following conditions:

- No frequent sales
- A history of at least one custom order

From the group of spare parts satisfying these conditions, an example is depicted in Figure 49

[12] Several reasons exist for a spare part with no previous operations to be suddenly requested by the market: some spare parts are required only after machines reach certain age, some machine models have fabrication defects that make whole batches in the installed base to require a replacement of a particular spare part without prior notice, finally customers trying to anticipate future machine breakdowns order extra quantities of spare parts that usually are ordered sporadically through emergency orders.

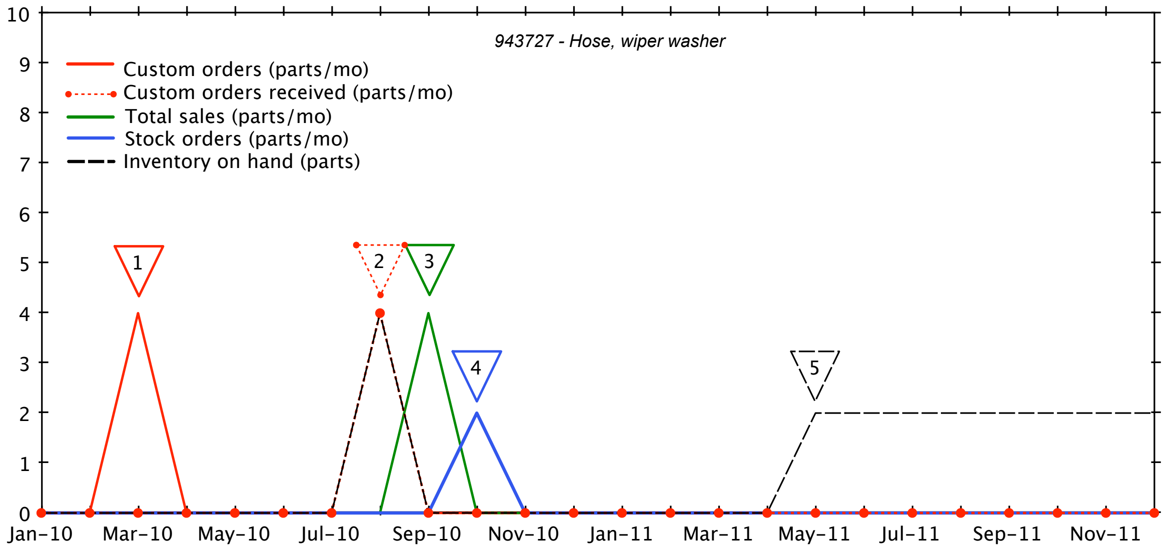

Figure 49. Historical behavior of a particular spare part with conditions similar to those of scenario 4

For the first two months of 2010 the part presented has no orders, sales or inventory. The history then develops as follows:

1. A custom order is placed
2. The parts ordered arrive, increasing the inventory
3. The parts are delivered, increasing total sales.
4. A stock order is raised.
5. 6 months later the parts ordered arrive (not shown), increasing the inventory. The inventory remains equal for the rest of 2011 due to zero sales or orders.

Figure 49 shows again how IOH SO increases due to misleading sales expectations. The spare part was not maintained in inventory before. Then, a sale from a custom order caused sales expectations to increase. As a consequence, the desired inventory increases and a stock order is made, with the posterior increase in inventory. However, contrary to the expectations, inventory does not deplete, and the spare part remains with no sales. The reason for the lack of movement is that sales for the spare part are sporadic, not frequent, which was precisely the reason why the part was not kept in inventory in first place.

As in the previous scenarios, the final consequence of the initial input in custom orders is seen in inventory more than one year later. Inventory of spare parts with no sales (called *dead stock* at UMG) has reached 20% of the total inventory in 2011 (Huertas, 2011). Causes for dead stock have been attributed mostly to exogenous factors as entry of new competitors and change in machine models. Scenario 4 presents a possible endogenous explanation for the accumulation of *Dead stock* at UMG.

7.9.1.5 Scenario 5: Pulse in custom orders with sinusoidal regular sales and delayed custom sale delivery

The past scenarios have assumed that custom orders are delivered to customers as soon as parts arrive to UMG, with a delivery delay equal to the average time to transport the spare parts from UMG Head Office to the customer site (2 weeks). However, a review of a sample of spare parts with customer orders and posterior sales revealed that often the delivery of the custom orders is done after several months (an example is Figure 46 which shows a delay of three months). Further inquiry with people directly related to the issue revealed two situations not known so far in the project:

1. After a customer has placed a custom order, and the parts arrive to UMG, often the customer does not collect the spare part immediately, but when the spare part is needed. Given that spare parts may arrive during 'rainy season' where there is little or no activity for the machines, customers do not collect the spare parts until the 'rainy season' ends, or even later if the spare parts are not needed yet. The result is that the delivery to the customer was estimated to occur around 3-5 months after the parts have arrived. In the meanwhile, the parts are kept in stock, although allocated to the customer.
2. Branches receive the custom orders directly from customers and redirect the orders to the Head Office. However, the order received by the Head Office sometimes is higher than the original order placed by the customer. Branches add the extra quantity in order to increase their own inventory beyond what is normally allocated to them. When the custom order arrives to the branch, the branch delivers what the customer originally requested and keeps the rest for inventory, supporting the transaction with a note registering a partial cancellation from the customer.

The result of these two situations is that the inventory on hand originated from custom orders (Total IOH CO) is not delivered in the time needed to transport the parts to the customer, but remains for a longer period of time in inventory.

In order to test the consequences of extra delivery delays of custom orders in the stock ordering policy, the formulation for the delivery rate of custom orders was adjusted from a first-order material delay to a twelfth-order material delay with an average delay time of 6 months[13]. Hence, orders are not delivered immediately after the parts are received but are delivered gradually with most of the parts being delivered after 6 months. Figure 50 illustrates the simulation output before and after the change in the formulation of the delay:

[13] The total length of the 'rainy season' is 5 months. Hence, the test illustrates an extreme case where parts are allocated to the customer but held in inventory during the whole 'rainy season' plus one month.

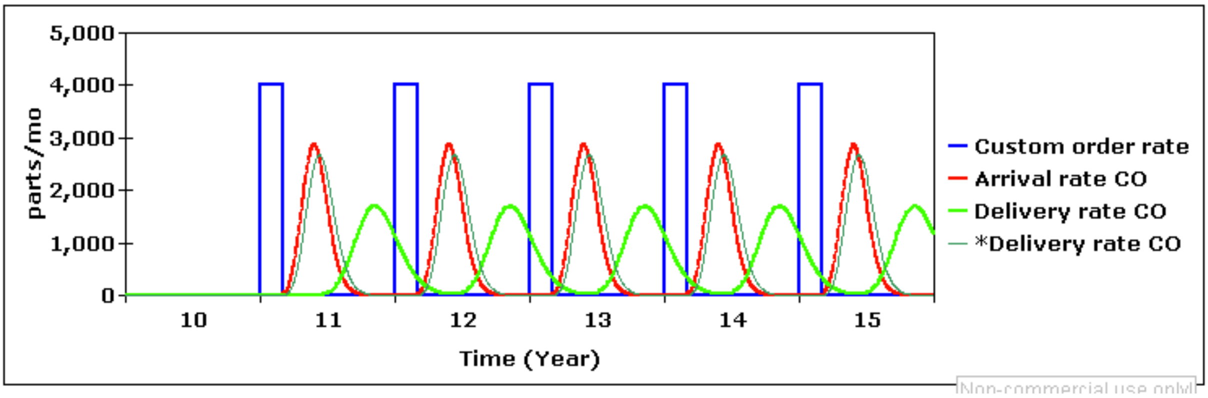

Figure 50. Responses of delivery rate to two different delivery delay formulations

Figure 50 shows a sample input for custom orders (*Custom order rate*), the arrival rate to UMG inventory (*Arrival rate CO*), the delivery rate to the customer with the new formulation for the delay (*Delivery rate CO*) and with the previous formulation (**Delivery rate CO*). It can be seen how with the new formulation parts arrived around 6 months later after the arrival rate and arrived dispersed in a span of approx. 6 months.

With the new formulation for the delivery rate of customer orders, a scenario was simulated as follows:

Exogenous variable	Value
Regular sales	Sinusoidal
Custom orders	Pulses

The simulation output is presented in Figure 51:

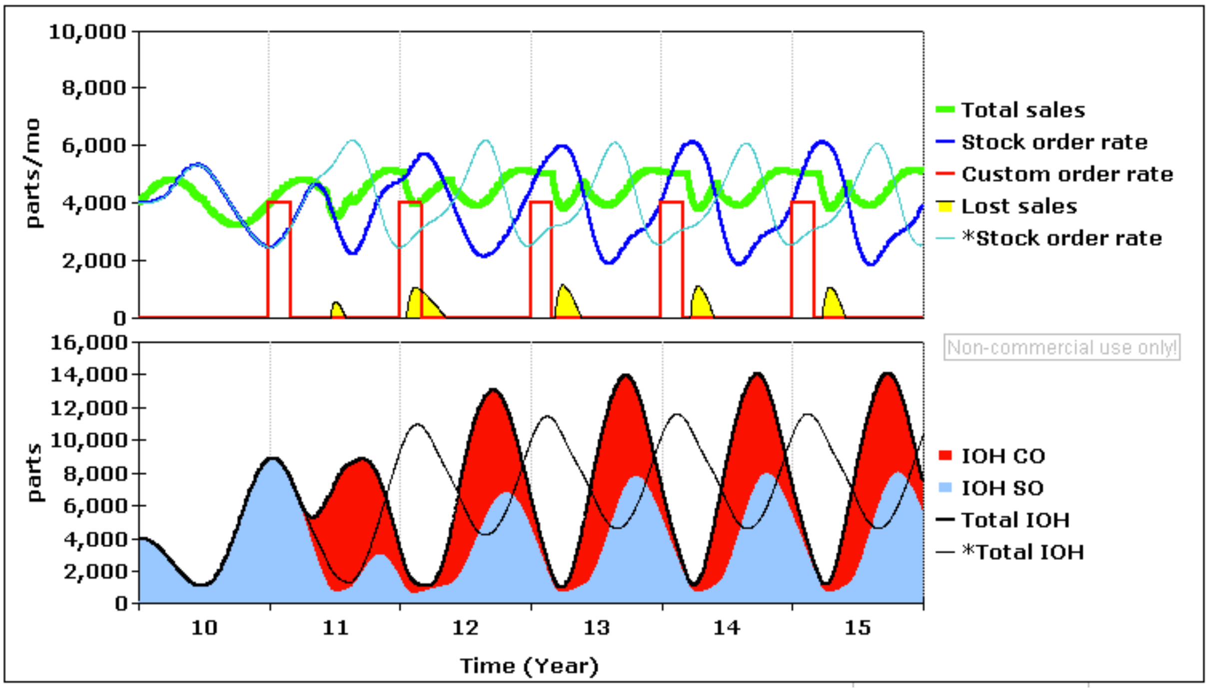

Figure 51. Simulation output for scenario 5

A new variable have been introduced to the graph above: *Lost sales* correspond to the regular orders that cannot be fulfilled due to insufficient stock (yellow fill). Also,

**Stock order rate* in light blue shows the base case for the stock order rate under the regular delivery rate formulation.

The first pulse in custom orders is introduced at the beginning of year 11; parts arrive 4 months later (not shown), increasing the inventory on hand from custom orders (at second half of year 11*)*. However, in this scenario the IOH CO does not deplete immediately but remains longer in inventory due to the higher delivery delay (red fill in the graph during second half year 11). During the time IOH CO remains in inventory, it is counted as part of the total inventory on hand (*Total IOH*). Hence, at half of year 11 the total inventory remains high, but the composition of it changes: Most of the inventory is allocated for custom orders. Since the difference in composition is not perceived by the ordering policy, higher *Total IOH* causes stock orders (*Stock order rate*) to decrease during at half of year 11 (loop B1 controls the high inventory by lowering orders). During the second half of year 11, all the parts from *IOH CO* are delivered, *Total IOH* decreases, total inventory decreases and in consequence stock orders rise again. However, the increase in orders cannot compensate the quick decrease in inventory and lost sales occur at the beginning of year 12 (yellow fill). Inquiry to participants showed that UMG does not have a mechanism to get feedback from lost sales. Hence, under the situation of lost sales no corrective action is taken.

At the beginning of year 13 customers place custom orders again and the whole cycle is repeated. From year 12 fluctuations are more aggressive: *Total IOH* reaches higher peaks because more *IOH CO* is accumulated, and decreases to lower troughs because stock orders are made too late.

The overall result is catastrophic: inventory is amplified even more than with the original delivery rate formulation (see reference run **Total IOH*) and still with periods of higher inventory, inventory shortages occur every year, generating lost sales.

In this scenario, the poor results are not mainly generated due to a misperception of sales, but due to a misperception of the inventory for the ordering process. *Total IOH* includes inventory that is already allocated to a customer (*IOH CO*). Since it is already allocated to a customer it cannot be used for regular deliveries, but the ordering policy takes it into account as if it could, ordering less than what otherwise would have ordered.

Does the inventory on hand from custom orders (*IOH CO*) at UMG represent an important fraction of the Total IOH as to have the implications mentioned in this scenario? Since no data exists that allows distinguishing between the IOH SO and the IOH CO, the simulation model was used to answer such a question. Historical custom orders are fed into the custom orders supply chain, as well as the estimated historical custom sales (both in red in Figure 52).

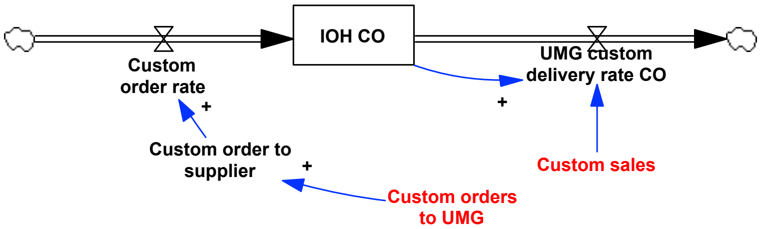

Figure 52. Diagram of partial test executed in scenario 5

The simulation output for the IOH CO would reveal the volume of the accumulation in inventory of parts waiting to be delivered. The results are presented in Figure 53:

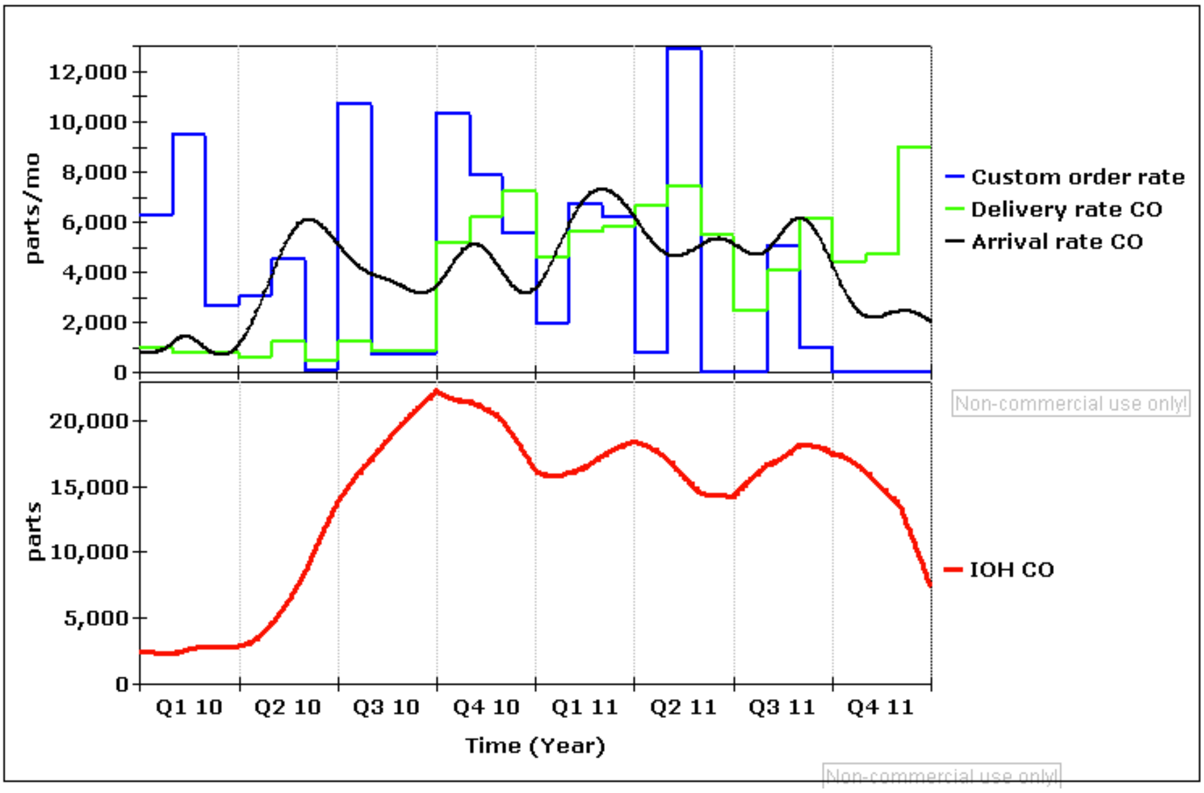

Figure 53. Simulation output for partial test in scenario 5

The graph on the top in Figure 53 shows the historical time series for custom orders (*Custom order rate*) and custom sales (*Delivery rate CO*), and shows the arrival rate of the custom orders to UMG's inventory on hand IOH CO (*Arrival rate CO*). The graph below shows the inventory on hand from custom orders (*IOH CO*). It is assumed that the initial value for IOH CO corresponds to an estimation of the parts received in the last quarter of 2009 (2500 parts).

During the first quarter of 2010 deliveries were close to part arrivals, thus, inventory was stable at around 2500 parts. However new custom orders were placed during the first quarter of year 10 for up to 10000 parts. Arrival rate increases during the second and third quarter of year 10, causing a similar increase in inventory. At the end of the third quarter of year 10, IOH CO reaches its peak at 25000 parts, which corresponds to 27% of the total inventory on hand on that date (not shown, 90000 parts). IOH CO remains higher than 10000 parts for most of the two years of historical data before it decreases to 5000 parts (13% of the total inventory). Such a finding is in contrast with the perceptions expressed by the participants during the second session: Participants expressed that in general most of the inventory was composed of the inventory on hand from stock orders (IOH SO), and that the volume of the IOH CO was negligible because parts for custom orders are delivered soon after the order arrives. However, the accumulation shown in the simulation output (Figure 53) shows that parts are not collected as soon as it is thought, and that the high quantity of parts involved in the operations (13%-27% of total inventory) causes permanent high levels of inventory from custom orders even if at all times there are parts being received and being delivered.

The IOH CO can be thought as a delay introduced by a stock in transit between the arrival of parts to UMG and the delivery of the parts to customers. Recognizing how much is in the delay means recognizing the size of the stock at any point in time. However, it is documented how people fail to recognize the accumulation of stocks “in transit” that act as delays (Sterman, 2000). Figure 54 illustrates a representation of the mental model at UMG:

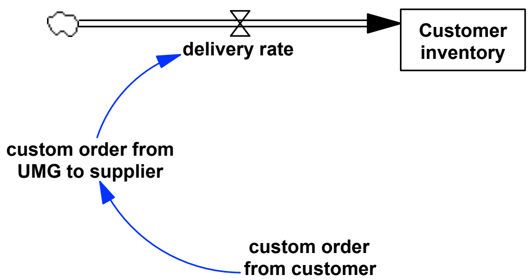

Figure 54. Representation of the mental model of custom orders at UMG

At UMG custom orders are thought as a continuous flow of orders from the moment the order is placed by the customer to the moment the parts are delivered and reach customer inventory (the only accumulation in the whole mental model). However, the case is different: Parts from custom orders accumulate in important quantities in stock at UMG during extended periods of time, as shown in Figure 53. The accumulation is presented in Figure 55.

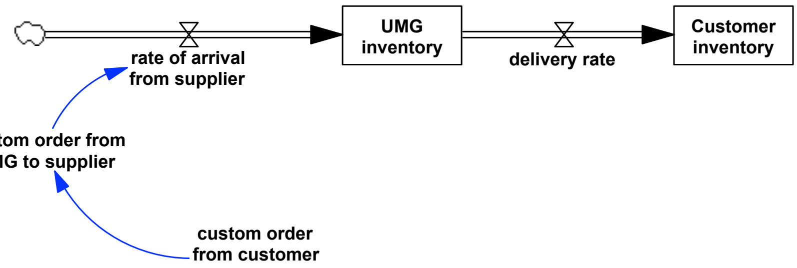

Figure 55. Model of custom orders with accumulation of inventory at UMG

Parts arrive first to UMG inventory and accumulate there until they are delivered to the customer inventory. Failure to account for such an accumulation can potentially produce undesired patterns of behavior in the system as the one portrayed in Figure 51.

7.10 Conclusions from model analysis

The model analysis offered conclusions to be reflected to the participants in the third session:

1. Taking total sales (regular + custom sales) as input for the stock order process introduces instability in the system. It causes the desired inventory to rise higher than what is required to adequately deliver the parts for regular sales. The increase in the desired inventory leads after a delay to the increase of the actual inventory. Hence, in a permanent presence of custom orders the level of inventory will be permanently be higher than required.
2. Taking total inventory on hand (IOH SO + IOH CO) as input for the stock order process introduces further instability in the system. A false perception of high inventory caused by accumulation of IOH CO leads to stock orders that are lower than what they should be on the light of the IOH SO available. When the IOH CO is depleted by custom sales, the scarcity of IOH SO becomes evident and sales are lost until new stock orders arrive. Hence, periods of high inventory are followed by periods of scarcity.

Both conclusions marked the end of the modeling efforts for the second iteration. The conclusions would be reflected to the group at the beginning of the third session as a possible explanation on how the ordering process causes instability in the supply chain and inventory levels higher than desired.

Chapter 8. Third group model building session

This chapter describes the preparation and activities undertaken during the third and last GMB session.

8.1 Preliminary work between the second and third sessions

The second iteration of the model revealed possible explanations for growing behavior and instability and supported some of the explanations with historical data matching the patterns of behavior of the model output. In order to verify that the structure and simulation output were in accordance to the behavior seen in the actual supply chain, an extra meeting was planned with two key participants in the period between the second and third session. The goal of the meeting was to examine if the causal structure and the data and simulation output of the scenarios 3, 4 and 5 were in accordance with the structure and behavior observed in the actual supply chain.

The result of the meeting was that the structure, although simplified, reflected the actual ordering policies and sources of information used in the supply chain. Also, the participants recognized the patterns of behavior presented by the scenarios and agreed with the causal explanations provided for each pattern.

The meeting did not pretend to give validity to the model, but to assess the likelihood that the scenarios presented based on few samples from data were recognizable by the participants. With that goal achieved, the preparation for the third session started.

8.2 Preparing the third session

8.2.1 Roles of team members

For the third session the roles remained equal than in the previous two sessions.

8.2.2 Purpose of the session

The third session would be devoted to reflect on the output from the simulation model built in the second iteration, to understand how the actual ordering policy creates instable behavior and growing inventory, and to find policies that could help to improve the current situation.

8.2.3 Agenda

A public and private agenda was developed as in the first two sessions. The session was planned to last 3.5 hours, 1 hour longer than the previous sessions, foreseeing that more time would be needed to understand the actual behavior and to reach consensus on change initiatives (if any emerged).

The goal of the third session was to find consented policies for improvement of the problematic situations defined in the problem definition. However, to define policies for improvement, participants would need to have a clear understanding of: (a) the problem to be solved, and (b) the causes of the problem. The original problem definition was described in broad terms: High inventory and instable orders. However, the findings from the model analysis suggested that the problem could be expressed more accurately in terms of the specific patterns of behavior found during the model analysis (scenarios 3, 4 and 5).

With this idea in mind, the plan for the third session was sketched as follows: (a) assess with the group if the specific patterns of behavior were perceived as problems in need for solutions. If the group believed that the patterns presented are problematic, then those patterns could serve as a refinement of the problem definition, (b) based on each specific problem definition, the team would introduce the participants to the causal structure generating each behavior, (c) once the structure was shared with the group and adjusted if required, then the participants would be in a better position to define policies for improvement that could lead to organizational change.

With the previous plan in mind, the activities planned in the agenda were:

8.2.3.1 Refined graphs over time

The first activity of the session was targeted to introduce the participants to three specific patterns of behavior that would summarize the particular situations to focus on for the rest of the session. However, care was taken that the team did not apply any value judgment to the patterns. Graphs over time would be presented initially just as common cases taken from historical data of orders, inventory and sales for particular spare parts. Value judgments would be avoided in order to prevent the modeling team from imposing new problem definitions to the participants.

8.2.3.2 Good or bad

Once the patterns of behavior were introduced, the team would verify if the participants perceived such patterns as problematic. Reaching consensus on the refined problem definition was an important step for the session. On the contrary, in the case participants did not recognize the situations as problematic, then searching for policies to improve such situations would have been meaningless.

In order to verify that the patterns of behavior were recognized as problems, participants would be asked to write down in couples if each pattern of behavior presented was good for UMG, bad, or both, and why. Then, each couple would share their perceptions with the others. The facilitator would, at the same time, write down the perceptions in the whiteboard. At the end of each pattern of behavior, consensus would be checked among participants in order to conclude if the situation was “good”, meaning that the graph did not represent a problem, or if the situation was “bad”, meaning that the graph did represent a problem. The output of the activity would be the final list of problematic patterns of behavior.

8.2.3.3 Model structure

Using as input the patterns of behavior specified in the previous activity, the modeling team would reintroduce the causal structure created by the group during the second session and explain how such a structure was generating the behaviors observed. Since a clear understanding of the causal explanations was critical, the modeling team would present the model structure in two steps: First, the team would make an overview of the whole causal diagram developed in the second session, and then the team would present an isolated, simpler stock and flow for each pattern of behavior in order to describe how the structure generated such behavior. Input from participants would also be welcome during the whole presentation of the model structure were any change on the structure needed. The output of the activity would be a consented causal structure explaining each pattern of behavior.

8.2.3.4 Policy elicitation

Once understood the problem and its causes, the next step would be to elicit a consented list of improvement policies. To achieve that, the group would be divided in couples. Each couple would write down possible policies to solve each problematic situation. Then the couples would share the improvements with the group while the facilitator would record them in the whiteboard in the form of causal diagrams. The idea behind the causal diagrams was that possibly the different improvements would be linked causally, so establishing the causal relationships among them would help to keep a holistic view of the efforts proposed and their possible relationships. Furthermore, recording the policies in such a way may help to distinguish between policies and indicators[14]. By doing that, the group could later focus on those policies that were actual policies rather than indicators.

After structuring the policies of improvement for the problems defined, the participants would vote for the improvements that appeared more effective and with more

[14] The modeling team assumed that some of the policies suggested by the group would really be indicators of performance.

feasibility to be implemented. The participants would vote by sticking pieces of paper on the whiteboard where the facilitator had structured the policies.

The results of the poll for each problem would then be reflected. A discussion of the most voted policies would test if there were consensus around any of them in order to define a final list of policies to be implemented.

Discussion

Luna-Reyes, et al. (2007) discusses the changes in the use of diagramming notation across the GMB sessions and concludes recommending to maintain consistency among sessions. Either if the sessions are using causal loop diagrams, or stock and flow diagrams, the diagramming notation should be maintained. However the modeling team decided to change the notation from stock and flow to causal diagramming for the activity of policy elicitation. The reason for such change was based on the urgency for simplicity during the elicitation process. The stock and flow diagram elicited during the second session reached a level of complexity that would have made the policy elicitation even more complex. Also, the policies to be defined were expected to cover a broad range of aspects of UMG. Hence, a stock and flow would have required a level of consistency in the notation that may have slowed down the process and made it more complicated

8.2.3.5 Plan of implementation

The final activity was to define a brief plan of implementation of the policies defined in the previous activity. Such plan would define a responsible and a brief description of the goal. The definition of the responsible would be left to open discussion from the group. The description would be developed after the session between the modeling team and the responsible.

8.2.4 Room layout

The layout of the room would be maintained as in the previous two sessions.

8.3 Activities executed

8.3.1 Refined graphs over time

Two situations were chosen as a way to reflect the results from the analysis of the second simulation model. For each situation, first, cases from historical data were presented (see other example besides those of the scenarios in Appendix 4). Then, a generic graph illustrated the generic pattern of behavior of the situation under discussion. The situations presented were:

8.3.1.1 Situation 1: Custom sales that amplify stock orders

Situation 1 compiled the findings of scenario 3 and 4 where the sales from custom orders would increase the overall sales rate, causing an increase in the stock orders (see Figure 56 and Figure 57):

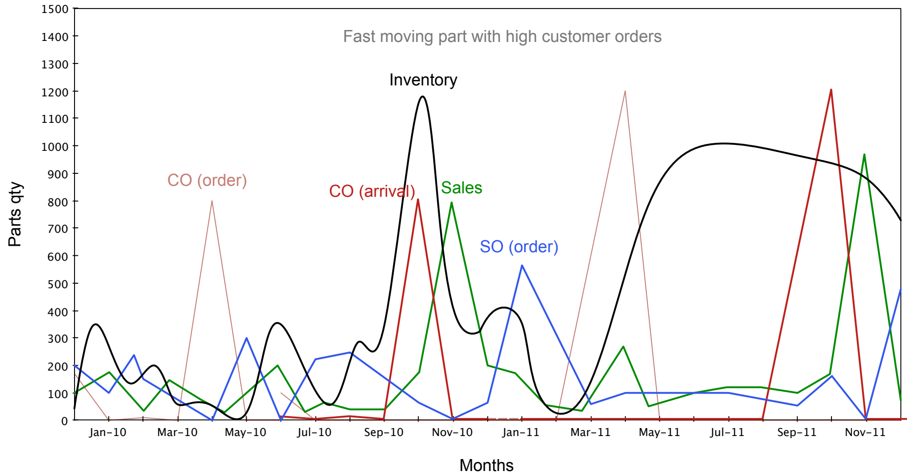

Figure 56. First pattern of behavior for situation 1

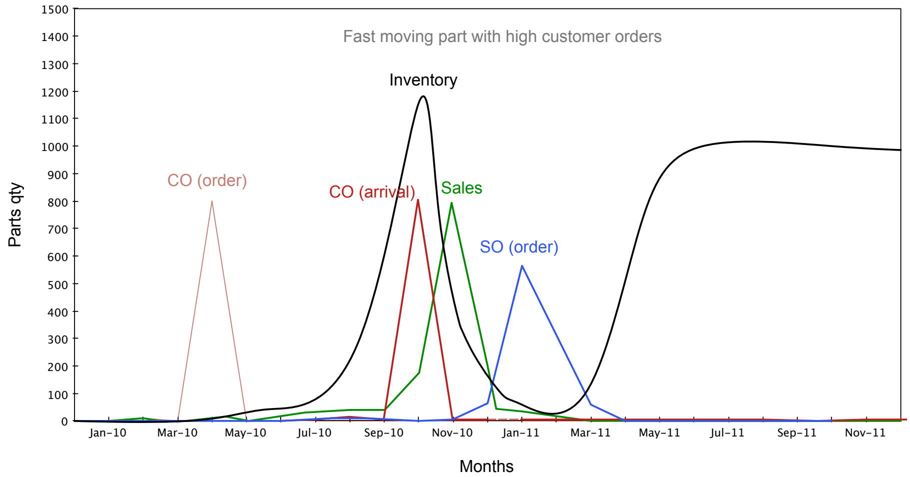

Figure 57. Second pattern of behavior for situation 1

Figure 56 and Figure 57 show the sequence of custom orders (light red), the arrival of custom orders (dark red), sales (green), stock orders (blue) and the final consequence in inventory (black). The pattern of behavior of the graphs resembles that of scenarios 3 and 4: Amplification in inventory due to misleading sales expectations from custom sales.

8.3.1.2 Situation 2: High inventory due to accumulation of custom orders pending to be delivered

Situation 2 compiled the findings of scenario 5 where the delay to deliver the parts coming from custom orders increases to up to 6 months, creating an accumulation of inventory from custom orders that represents an important fraction of the total stock. Two figures were presented to illustrate such a situation, Figure 53, showing the volume of total accumulation of parts from customer orders, and Figure 57:

Figure 57. Pattern of behavior for situation 2

Figure 57 shows how after customer orders arrive to UMG (dark red) inventory grows (black). Inventory remains high after the parts have been received for the next 6 months because the parts take that amount of time to be delivered. Once delivered, the inventory falls back to its original level.

8.3.2 Good or bad

Once the situations were presented to the group, the participants were given formats (see example on Appendix 3) to write down if the situations could be qualified as good or bad for the company and state why. The activity, originally planned to last 15 minutes, took twice more. The reason is that participants took longer than expected in understanding the graphs presented as to be able to give a value judgment on them.

After the participants finished their work in couples, they shared their perceptions with the group. The facilitator recorded the opinions from the group in the whiteboard.

8.3.2.1 Situation 1: Custom sales that amplify stock orders

The recordings for the situation 1 is presented in Figure 58 (left side for good and bad activity, right side for the policy elicitation activity to be described further in the document):

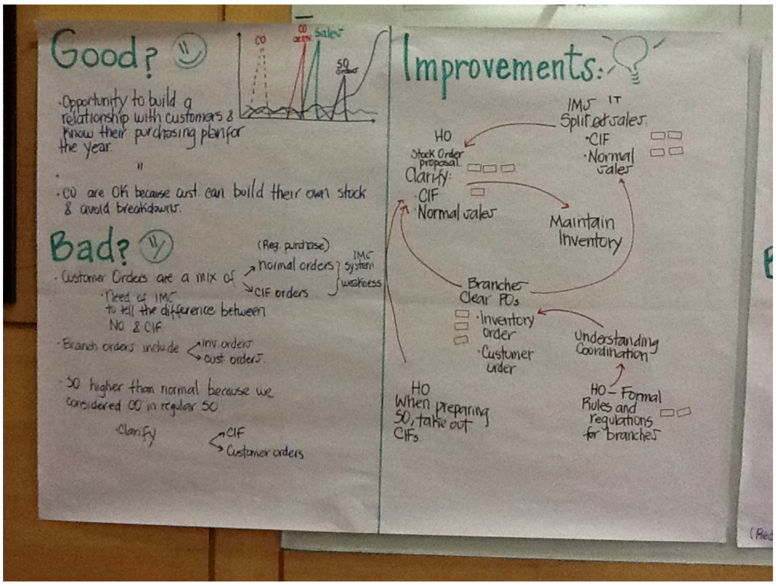

Figure 58. Recordings of 'good or bad' activity and policy elicitation for situation 1

For situation 1, the participants considered that there were two good aspects related to it:

- If the custom orders followed a yearly pattern, UMG could plan according to their purchasing behavior.
- The fact that customers kept their own inventory allowed them to avoid breakdowns due to lack of part availability.

The bad aspects shared by the group were:

- Custom orders and regular orders were mixed.
- Stock orders were being higher than normal because custom sales were considered for the stock orders

After deliberation, the group agreed that the situation was in general bad due to the consequences in high inventory.

8.3.2.2 Situation 2: High inventory due to accumulation of custom orders pending to be delivered

The recordings from the facilitator for the second situation are presented in Figure 59 (left side for good and bad activity, right side for the policy elicitation activity to be described further in the document):

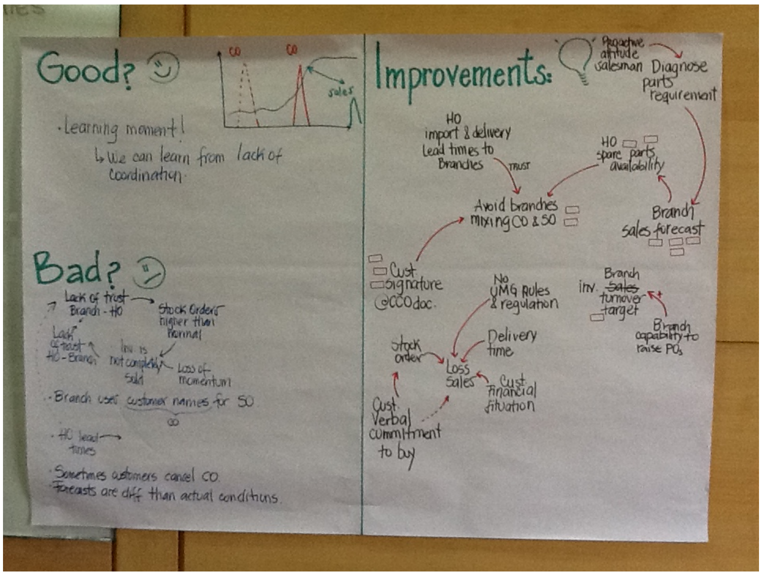

Figure 59. Recordings of 'good or bad' activity and policy elicitation for situation 2

Regarding what was good from the situation, a participant enthusiastically expressed that it represented a learning moment to understand how lack of coordination between orders and sales was leading to high inventory of parts from custom orders. However, it would be when discussing what was considered bad from the situation 2 when the session reached a turning point.

The situation 2 illustrated how longer delays in the delivery of inventory allocated to custom orders caused periods of high inventory. However the modeling team did not deepen on the reasons why the delays were longer. In contrast, the group quickly agreed that a situation that leads to high inventory was bad, and quickly moved to explanations on why the parts were taking longer than expected to be delivered. The discussion set mainly between the spare parts manager at the head office and the branch manager.

The discussion could be described as follows: Branches are the point of sales for the spare parts. Hence they are in a closer contact with clients and the trends of the demand. Based on their knowledge of the market, branches send monthly suggestions to the Head Office of the parts that they need in inventory to fulfill the demand of regular orders. The Head Office then sends the spare parts to each branch. However, the head office does not set the quantity to send to each branch based on the suggestions sent by the branches, but on calculations based on sales estimates made by the Head Office itself.

The result, according to the branch manager, is that branches usually get fewer parts than what they require to keep an adequate inventory. Without adequate inventory, branches cannot fulfill satisfactorily the demand from regular orders. Only after several months, Head Office reacts to the changes in the demand. This delay is perceived by the branches as a long lead-time from the Head Office to deliver adequate quantities of parts. From that point, the facilitator recorded the discussion in the following causal diagram in

Figure 60 (slightly edited from the original to increase consistency with the terms used in this document):

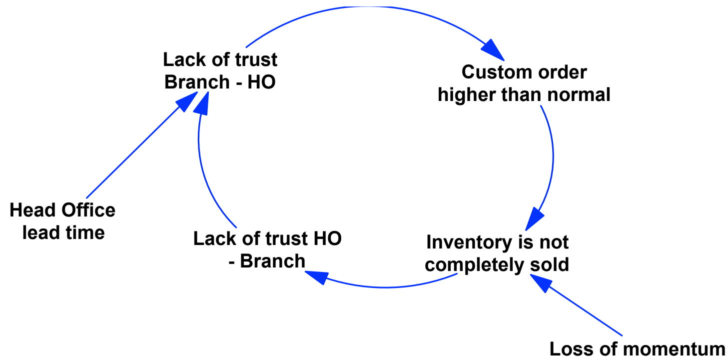

Figure 60. Policies elicited for situation 1

Long lead times on deliveries from the Head Office to the branches (*Head Office lead time*) cause lack of trust from the branch to the Head Office (*Lack of trust Branch-HO*). Because the branches did not trust that the Head Office would deliver the suggested quantity of parts on time, branches inflated the amounts of parts ordered by customers in custom orders (*Custom order higher than normal*) in order to store the excess of parts in their inventory. Such excess was intended to compensate for the lack of parts in inventory due to the long lead-time from Head Office. However, sometimes the excess of inventory is not sold soon after received (*Inventory is not completely sold*). The inventory then remains at the branch. When the Head Office perceives that the inventory at the Branch is higher than what is should be and determines the reason, the Head Office looses the trust on the suggestions sent from branches (*Lack of trust HO - Branch*). Lack of trust from Head Office leads to even lower deliveries to branches, which reinforces the original lack of trust from branches to Head Office.

In the case of UMG, a reinforcing feedback loop of mistrust was taking place, potentially causing larger custom orders and higher amounts of inventory.

The conclusion of the group was that situation 2 was considered a problem. The revelation of such dynamics added an additional component to the session. Besides working on the situations prepared by the modeling team, the new dynamics elicited would need to be included in the remaining activities of the day.

The result of the 'good or bad' activity was that the participants identified the two situations presented by the team as problematic behaviors. By recognizing the situations as problematic, the group would potentially be more engaged in finding possible solutions. Additional outcomes from the activity were:

- The participants gained an understanding of the situations presented enough for them to be able to discuss between them if the situations were good or bad and why.

- The group introduced new dynamics in the discussion related to trust between branches and Head Office and the effect of mistrust in the custom orders and inventory.

8.3.3 Model structure

Once the situations were recognized as problems. The modeler proceeded with the presentation of how the system structure was generating them. In order to maximize the time of the session available for the activity of policy elicitation, the modeler briefly presented in the whiteboard the complete model built during the second session and then showed how a substructure of that model was generating the problematic situations. For both situations, the substructure included some elements that were not actually included in the simulation model but that were part of the discussion of the group.

Figure 61 shows the piece of substructure built by the modeler in the whiteboard in order to explain the structure causing the situation 1. It can be seen how the structure resembles that of Figure 29.

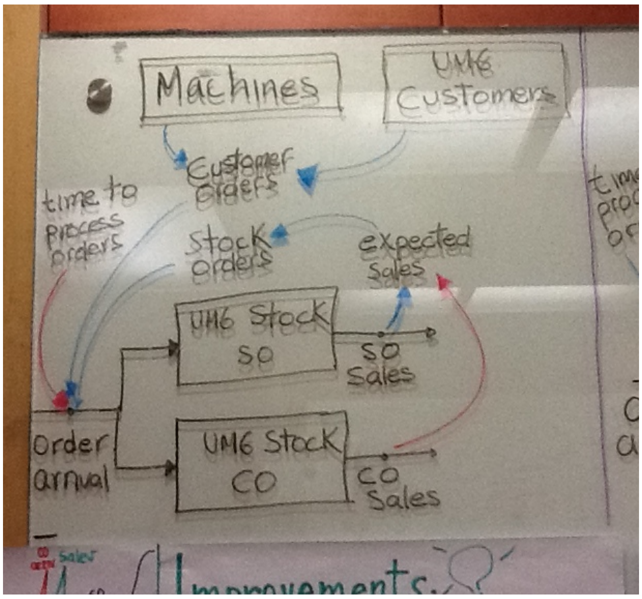

Figure 61. Substructure for situation 1

In the case of situation 2, the author presented a diagram that summarized the discussion held by the group about phantom orders in terms of the stock and flows involved (Figure 62):

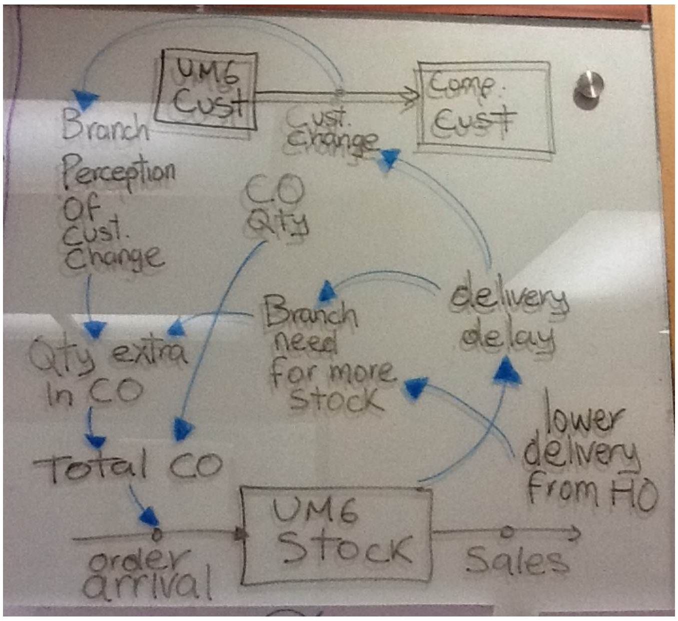

Figure 62. Substructure for situation 2

The diagram illustrates how a lower delivery of spare parts from the Head Office leads to a need of more stock from the branch. At the same time higher delivery delays can potentially lead to customers changing (*Cust. change rate)* from UMG (*UMG cust*) to a competitor (*Comp. cust*). Customers changing to competitor would trigger a *Branch perception of customers change*. Customers changing and the need for more stock would lead to *Qty extra in CO*, that is, the extra quantity ordered by the branch in name of the customer to refill the branch's regular stock. Such extra quantity would be summed up with the original *Custom Order qty* to obtain the final *Total CO*: The total quantity of parts for custom orders. Hence, the dynamics of phantom orders were related to the causal structure that the group had been building in the previous two sessions.

After the causal structures were presented, the next activity would be to elicit possible policies for improvement of the problematic situations defined.

8.3.4 Policy elicitation

To elicit the policies from the group, the participants were organized in couples, each couple wrote down the policies for improvement. After, the results were shared with the rest of the group. The facilitator recorded the discussion in terms of causal diagrams.

8.3.4.1 Policies for situation 1

The policies discussed by the group were recorded by the facilitator on the whiteboard (see the right side of Figure 58). Once all the policies were recorded, each participant voted for the policy or policies that the person believed should be implemented. The votes were made by sticking small pieces on paper on the policy chosen on the whiteboard. Each person could vote for as many policies as desired. Figure 63 illustrates the policies elicited and the most voted ones in red.

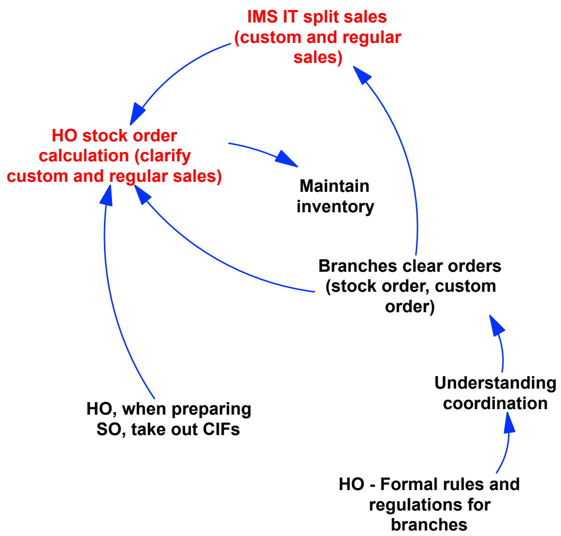

Figure 63. Policies for situation 1

The improvement initiatives could be separated in two groups:

- Policies intended to standardize the storing and reporting of information from the branches: *HO – Formal rules and regulations for branches, Understanding & coordination* and *Branches clear orders (stock and custom order)*
- Policies intended to improve the storing and usage of information about orders and sales at the Head Office: *IMS IT split sales* and *HO stock order calculation (clarify custom and regular sales)*.

The most voted policies were those targeted to the Head Office, that is, the ones related to the distinction in the central information system and in the stock order calculation of the regular and custom sales. The main goal of the policy would be to update the information system and the ordering calculation, so that sales records are separate by sale type. Once separated, only regular sales would be taken into account for the calculation of the stock orders.

8.3.4.2 Policies for situation 2

The facilitator recorded the policies discussed for the situation 2 (see right side of Figure 59). The policies, including the most voted one is presented in Figure 64:

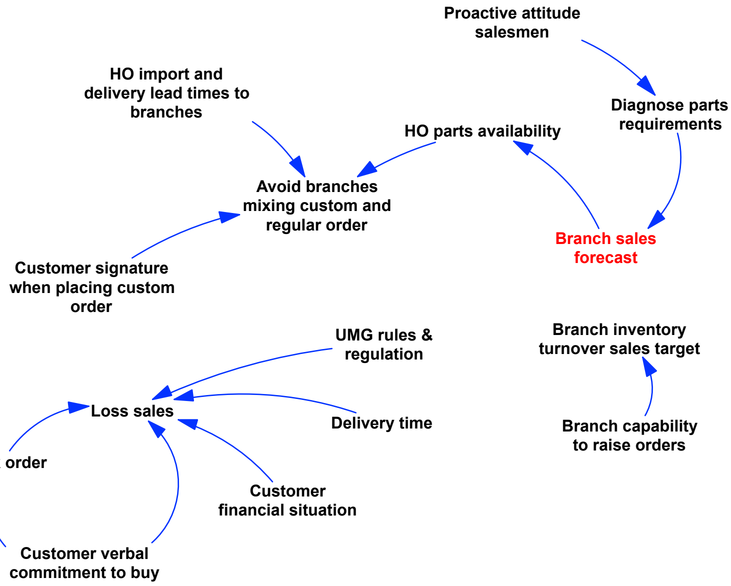

Figure 64. Policies for situation 2

The policies can be grouped as follows:

- Policies intended to improve the estimations of the demand from branches. Better demand estimations would lead to better delivery suggestions from the branch to the Head Office. Better suggestions would lead the Head Office to regain the trust in the branches. If branches can be trusted, then the deliveries from HO to branches could be based on the suggestions made by the branches rather than on HO estimates (see *Proactive attitude salesmen, Diagnose parts requirements* and *Branch sales forecast*).
- Policies intended to increase the accountability of the branches for the suggestions for part deliveries sent to the Head Office. To achieve that, branches' target for inventory turnover would be linked to their suggestions, so that bigger deliveries from HO to branches would lead to higher turnover target for the branch (see *Branch capability to raise orders* and *Branch inventory turn over sales target)*
- Policies intended to avoid cancelled orders or lost sales, such as studying in advance customer's financial situation, reducing delivery time and others (see *Loss sales, Customer financial situation, Delivery time, UMG rules and regulation* and *Stock orders*.

The most voted policy was to improve the sales forecast from branches so that deliveries from Head Office to branches would be based on such forecasts rather than on the delayed information used by the branch. By delivering the right amount of parts to the branches, branches would not need to place inflate the orders to the Head Office anymore, potentially avoiding the inventory in excess described in situation 2.

8.3.4.3 Final consensus on policies to be implemented

The facilitator reflected to the group the two most voted policies and then initiated a brief round of open discussion by making the question: How such policies can be implemented?

From the two most voted policies, the policy for situation 1 involved mostly the Head Office, and the policy from situation 2 involved mostly the branches. The Head office should differentiate the sales information based on the sales type (custom, regular, emergency). The branch should provide sales forecasts supported on better calculations. In the middle of the discussion was the matter of trust from both sides (branches and Head Office), trust led to the issue of transparency. Branches could not know which parts and which quantity the Head Office would deliver to them every month. Head office could not know the criteria behind the sales forecasts expressed in the branches suggestions for future deliveries. Hence, it was evident that an atmosphere of distrust reigned between both parties.

The modeling team suggested that the information shared between HO and branches was limited to the suggestions from branches to HO. HO was not really sharing any information to the branches. The point made led to a discussion that eventually allowed the group to achieve consensus on one solution: The branches would make explicit the calculations made to get the forecasts of sales in order to make the delivery suggestions more transparent. 'In exchange', the Head Office would send to the branches every month an estimate of the quantities that would be delivered to the branch for the next 2 months. By doing so, the branch could know in advance the upcoming inflows of spare parts, and could give feedback to the Head Office on the cases where the estimate was considered incorrect. More information sharing from Head Office to branches would eliminate the need from branches to inflate the custom orders from customers. Potentially solving the problem of high accumulations of inventory due to custom orders waiting to be delivered.

In addition, the Head Office spare parts manager recognized the need to separate in the central system the records for sales and inventory based on the order type (regular, custom, emergency).

Finally, the modeling team put into consideration the issue of the ordering policy. In 5.3.1 data revealed that the ordering policy used by UMG does not follow a formal calculation but is rather done mentally in an adjustment process made by the inventory manager. The formalization of the calculation was presented as a key step in making the ordering process more transparent, predictable and traceable. The HO spare parts manager asked the modeler to make a comparison between the behavior of the ordering policy registered in the original spreadsheet file (as described in 5.3.1) and the behavior of the policy derived from the mental adjustment made by the inventory manager (as described in 5.3.2). The group agreed that the results of the analysis would be used in the future to decide which policy to use. Once a policy was chosen, the policy would be formally stated, documented and followed.

After achieving a final consensus, the final activity was a definition of a plan for implementation.

8.3.4.4 Plan of implementation

For the group it was clear who were the responsible to lead the actions to be taken: that is the spare parts manager at the head office and the spare parts manager at each branch. Further details of implementation were to be defined between both with support of the modeling team.

The definition of the people responsible for leading the policy consented by the group marked the end of the third and last GMB session.

Chapter 9. Discussion of the use of GMB at UMG

9.1 Cooperation from the participants

The CEO at UMG welcomed from the beginning the idea of using GMB to develop the simulation model for this thesis. However, in a company where there is a permanent program of basic education in systems thinking, this fact should not lead to any conclusion further than to think that the project enjoyed full support from upper management. He saw in GMB a possibility to increase the coordination among the actors in the supply chain and a learning opportunity.

The spare parts manager, who acted as gatekeeper in the project, welcomed the idea of the use of GMB, although with a different reason than the CEO. For her, the main benefit was in being able to share "her" problems in the supply chain with the others. Other participants welcomed the idea with what appeared less visible interest. Once the CEO supported the idea, they "should" participate. During the sessions, people were always active and collaborated with all the activities.

9.2 Understanding of the participants of the activities and project outputs

People were active in the sessions; however, I realized that being active does not necessarily mean being active productively. Often, we (facilitator and recorder) would find, after 10 or 15 minutes, that one participant had been doing an activity in the wrong way, just when it was time for all participants to share their work. Hence, the challenge was not making the participants to cooperate but also to cooperate with the right result. With the time we realized the importance of being clear in the instructions, and the importance of repetition. Never once more was too many. This proved to be true for us in the third session.

In the third session, to facilitate the work of the participants, we provided them with templates where they could write down what they were asked for (see an example in Appendix 3). In those templates, we decided to include, for easier reference, a small graph of the pattern of behavior that the participants should refer to. However during the session, each activity that involved a template required an explanation of the graph. In total, we may have explained the graph about five times. When it was time to explain the causal structure generating the graphs, our perception is that the participants had internalized the dynamics involved in the graphs to a point where the structure was easy to relate to the behavior. We did not have that perception at any point before in the project. Unfortunately, we did not measure scientifically the participants' understanding at any point during the session.

9.3 Learned lessons from the GMB sessions

9.3.1 Activities take longer than what they look

One of the problems faced by the modeling team during the first session was the lack of time. Activities in general took longer than what we predicted. The following table summarizes the activities executed in the session and the planned duration, the actual duration, and a running total (in minutes). To gather the time durations I used the video recorded from the session.

Activity	**Sub-Activity**	**Planned duration**	**Actual duration**	**Running total**
Introduction to session		**5 min**	**8 min**	8
Influencing variables	Explanation of activity	**2 min**	**4 min**	12
	Writing down the variables	**3 min**	**7 min**	19
	Sharing variables in whiteboard	**5 min**	**17 min**	36
	Explanation of prioritization	1 min	2 min	38
	Prioritization and results	5 min	6 min	44
Graphs over time	Explanation of activity	**5 min**	**11 min**	55
	Drawing from participants	**10 min**	**15 min**	1:10
	Sharing in the table[15]	**0 min**	**5 min**	1:15 – 3
	Sharing to the group	**10 min**	**20 min**	23
	Reflector feedback from clusters	5 min	4 min	27
	Break	5 min	13 min	40
Concept model	Bathtub analogy	5 min	3 min	43
	Presentation of concept model	10 min	12 min	55
GMB	Modeling session	**60 min**	**35 min**	1:30

The table shows in bold the activities for which the planned duration and actual duration differed the most. In general, the activities previous to the modeling session itself took 30 minutes from it. This caused the resulting model to be a very simplified one.

9.3.2 Others

Other learned lessons are listed below:

- Explaining what is a variable is quite complicated. It should be better planned so that people doesn't get biased towards an example but also is not left alone with a fuzzy definition. It really needs a concrete definition.

[15] This activity was not originally planned. The facilitator forgot to tell that the activity was in couples, so this had to be improvised to reduce the graphs to share (and time spent in the activity)

- When modeler and reflector are doing an activity and the reflector is helping the participants, the reflector must be careful not to interrupt or take the facilitator's role.
- In the script of graphs over time, when explaining the activity, the example should be clean of specific numbers. Asking for detailed figures of a variable to plot it in the graphs will lead participants to pursue higher accuracy than needed, will make them take more time and will lead to less graphs at the end. In contrast, setting a common time horizon should be helpful if the people are from the same company and we are not dealing with a very messy problem. Probably it is better to explain that we are interested mostly in the pattern of behavior than specific figures.
- At the end of graphs over time, the feedback from the reflector is key. A bad reflection can lead to a perception that the activity was useless.
- With shy cultures where there are also language difficulties, "reflective listening" becomes harder because people, more due to lack of understanding than to real agreement, will assent to what the facilitator says.
- In general, the interventions of the recorder must be planned so that they do not interfere with the role of the facilitator
- When presenting graphs to the participants, the graphs must be first introduced, explaining what each line and each color represents. It must not be given for granted that if the variable was already used in the model then it does not need to be explained in the graph.
- Repetition is useful when it comes to understanding complex patterns of behavior. Several activities can be organized around the same patterns. After some time participants will internalize the pattern .

Conclusions

Group model building and system dynamics simulations helped UMG to structure the problem of the spare parts supply chain around the behavior of two variables: High inventory level and order instability. Analysis of simulation output and participants' input revealed the possible causes for such problematic behaviors:

- UMG's ordering policy to the supplier introduces instability in orders by amplifying changes in customer demand. Furthermore, the policy in use is not formalized in a procedure but is product of the mental calculation of the inventory manager.
- The perception of sales used in the stock ordering process includes sales that are not delivered from the regular stock (custom and emergency sales). Hence, perceived sales will be higher in the presence of custom or emergency sales. Higher sales expectations lead to higher orders and eventually higher inventory on hand. However the excess of inventory on hand is not justified by an increase in regular sales but by a misperception in the sales, creating unnecessary situations of high inventory.
- The perception of the Total inventory on hand (Total IOH) includes inventory accumulated from all three types of orders rather than only from the inventory on hand from stock orders (Total IOH SO). Hence, in the presence of constant custom orders, the perception of inventory will be higher than what it should be. Such a misperception leads to a distortion of the information used for the stock ordering process and further instability in the orders.
- Branches inflate custom orders placed by customers before transmitting the order to the Head Office in order to keep some of the spare parts for their regular stock. Accumulation of regular stock due to inflated orders from branches have led the Head Office to deliver less spare parts to the branches until the accumulation decreases. Lower deliveries from Head Office causes branches to inflate custom orders further more, creating a vicious cycle that can lead to high accumulations of inventory.

Once the causes for the problematic behavior were identified, the group committed to execute the following actions towards the solution of the problems:

- Formalize the stock ordering calculation at the Head Office. The decision of which stock ordering calculation should be used will be based on the conclusions of a new system dynamics study that will compare the dynamic implications of two possible ordering calculations known by officers at UMG.

- Correct the sources of data used to create the perception of sales and inventory by distinguishing between the different sales and inventory types. Once the distinction is made, only regular sales and IOH SO should be used in the stock ordering process.
- Share more information between branches and Head Office. In particular, Head Office should sent to the branch a monthly report of the parts to be delivered the next two months. Branches should provide supporting information on the monthly demand forecasts and delivery suggestions they send to Head Office. Information sharing will lead to more transparency, trust and less need from the branches to inflate orders and from Head Office to deliver fewer parts than what branches suggest.

Although commitment to the actions just presented still needs to pass the test of time, the actions were decided in consensus among the participants rather than by the exercise of power from a particular person or by mutual concessions. In this sense, GMB proved to be a successful method to reach consensus toward actions.

Quantitative simulation permitted to reproduce in the model situations in which cause and effect are distant in time. Results of the analysis of model behavior provided the most relevant conclusions to be reflected to participants in the GMB sessions. Hence, computer simulation proved to be a powerful complement for GMB.

Critical reflection

On model validity and group reality

One of the basic validity tests of a quantitative simulation model is a reference mode reproduction test. As this project involved quantitative simulation, I always looked forward to reproducing the reference mode of historical inventory, which was the central time series of the project. However, what to do if the model elicited from the group does not reveal the structure required for reproducing the reference mode? In my case, the model that resulted from the first session was oversimplified, and the model that resulted from the second session was probably overcomplicated. It included a scope that was far out of the time limits of the project. In order to reproduce a reference mode, I would have needed to alter the model elicited by the group, but then, ownership from the participants could be affected if the model presented in the next session was too different from the model left by the group. That was a permanent trade off I faced along the project: strive for a realistic model that reproduced 'the' reference mode? Or work with the model built with the participants (or a sub section of it in the worst case).

I chose to stick to the second option until the end. The reason was simple: part of the GMB process involves the construction of a common reality in the group. The model built by the group reflected the mental models of the group, their reality. More than once I felt the temptation of 'falling' into the role of a consultant, a person who offers a 'better' reality. A case in point was the introduction of the concept of inventory turnover into the model. Turnover is one of the goals upper-management uses to evaluate the performance of the spare parts supply chain. However, during the first session, where the most relevant variables were being discussed, nobody mentioned inventory turnover. In special a discussion on the question if high inventory was good or bad could have been closed by introducing the concept of turnover. Still, anybody used the turnover not even once in the session! For the second session, I decided to act for a moment as a consultant, and to illustrate how turnover could solve the discussion of the goodness of high inventory by relating it to sales. After I introduced the concept to the group, the group did not even mention it while building the model. I realized that the participants just did not think in terms of turnover, and although I thought they should, the GMB session was not the place to develop that type of consultancy.

The final simulation model does not include the turnover. It is probable that the conclusions from the model would have been richer if the model had included it. But would the participants have related to such conclusions? After the sessions there, my intuition tells me that most of them would not have even understood the conclusions. It was just not their language.

Was the model useful? The second simulation model represented a small subsection of the model developed by the group. Even being a small model, it revealed already important insights into possible causes for high inventory and instability. With an added benefit: all the participants could relate to its conclusions.

Is the model valid? The model represents the reality of the participants, at least a subsection of it. The participants related to the model structure and its output. To that extent it is a valid model. However, it does not fully reproduce the historical behavior of the system as a whole, it does not contain all the relevant structure required to do it, hence, I did not use the model to test policies. I considered it was not comprehensive enough. The policies that the group defined in the third session cannot be tested on this model. Testing such policies opens an excellent opportunity for a second phase of the project.

I spent a considerable amount of time on activities that led to no visible result because I was cached in the middle of the dilemma between modeling 'the' reality and the group's reality. By experience now I know that those two purposes can be different. My perception is that if I had modeled 'the' reality, I would have developed a more comprehensive model, where even policies could have been tested. Would have those policies been implemented? The chances appear to be lower than when using the GMB approach, although then the conclusions are more uncertain. That is the new tradeoff I face.

On the use of scripts

We used the script of 'Graphs over time' in order to gather dynamic stories about past behavior of the system and get an idea of the behavior over time of key variables. However the activity took most of the first session, the stories were not so informative, and the graphs could not be used as reference modes because they diverged from the historical data. Did we set the right goals and time for the script? In the context where this script has been documented (University of Albany), sessions last entire days, and the script is used in a context of other scripts. I found that before using a script, the purpose of the script and the way it articulates with the rest of the session must be as clear as possible. Leaving space to experimentation led in our case to partial success.

Further research

Several topics appeared as potential candidates for further research:

- A study of the dynamic implications of the "fixed-order time period model" in a supply chain with material and information delays, feedback and non-linearity.
- A simulation model to test the policies elicited during the third session.
- Study of the supply chain under uncertainty in the ordering lead times

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Appendix 1. Agenda for the first GMB session

The agenda for the first session was developed in the following table. The public agenda corresponds to the section delivered to the participants. The rest of the columns in the table were intended only for the project team.

Time	Public Agenda	Team Agenda	Roles and activity plan	Place in the room
1:15		Set up room	- Fill the walls with paper - Put down projector curtain - Set papers for "Influencing variables" on whiteboard A - Distribute enough white sheets to each table - Put Ad: please enter the other door on door 2.	
2:00	Introduction	Introduce three sessions Introduce today's agenda	**2:00 – 2:10** - J: Make presentation PPT - M: Deliver agenda -P: Attend presentation	J: Projector
2:10	Influencing variables	Individual variable listing (on sheets) – 5 min - Free criteria - Interdepartmental variables Variables sharing (mirroring in flip-chart) – 15 min - Go through participant's variables (including new) - Check if organizational units missing and suggest Variable prioritization (6 variables with most sticky dots) – 5 min	**2:10 – 2:15** - M: Explain activity and ask to start - J: Write the question on the whiteboard as facilitator explains activity: "What are the key variables affecting the process and outcomes of the spare parts business?" Deliver white sheets of paper & take out projector curtain - P: Attend explanation and start writing **2:15 – 2:25** - M: Ask each participant's variables (3 per p.). Make clear meaning, check consensus and tell reflector to write down. If meaning is unclear asking for units of the variable may help. Can add words as "level of" of "rate of" if natural to train participants. - J: Write down in the flip-chart the variables as facilitator instruct, reflect if all organizational units are included and advise facilitator - P: Confirm meaning of variables as facilitator asks **2:25 – 2:28** - M: Ask participants to stand up and reflect on which variables are priorities for the spare part business. Each variable they think is priority they should put a sticky dot on it. After the reflector has underlined the variables, the facilitator reads them aloud and makes sure participants know which are they. Clarify that is not that we forget the others; we just have chosen a place to start.	J: Main whiteboard J: Whiteboard A

			- J: Counts quickly as they finish adding dots, which are the variables with most of the dots and takes the ranking of the first six, underlines the variables in the flip-chart paper. Announces the ranking to the facilitator. - P: Stand up and put the sticky dots as needed, attend to the ranking of the top 6.	J: Whiteboard A
2:30	Dynamics	*Graphs over time* - Use prioritized variables + relevant for each person (40 min)	**2:30 – 2:35** - M: Erase main whiteboard. Show example of how to build a graph over time. Then ask to do it for as the most important of the top 6 variables defined before. Asks to do it by couples according to how they are seating using the special paper they already have. One per piece of paper. Give option to put hoped, expected and feared behavior. If they consider any other variable important not among the six can make it. If the couple disagrees can make different. - J: - P: Attend explanation **2:35 – 2:45** - M: Help participants if needed walking around the room - J: Help participants if needed walking around the room - P: Make the graphs over time **2:45 – 2:55** - M: Asks for the "best stuff" variable to the first couple, hold it in front and ask a person from the couple to explain it. Then give it to reflector. Keep doing it for the rest. Clarify timescale. - J: Take each graph and cluster it on the wall. - P: Explain their graphs **2:55 – 3:05** - M: After finishing with all the variables, asks the reflector: "What have you done there?" - J: Explain clusters, tries to summarize dynamics that help to characterize the problem that emerges from the participants' graphs. Ask the group to suggest names for the clusters. - P: Attend and participate according to invitation from the reflector	M: Main whiteboard J: Flip-chart paper 1 J: Flip-chart paper 1
3:05	Policies	List of momentum policies	- M: Ask participants to write down in a sheet of paper the policies that they would put in place NOW to improve the situations described before. What would they suggest to do? Collect pieces of paper as people finish. Tell them we will make a list, and we will review them again in the last session to see if something has changed. - J: Prepare while people write things down the projector curtain for the	

			concept model. - P: Write down the policies they can imagine	
3:10	Introduction to group modeling	*Concept Model* (15 min)	- M: Observe the group and clarify if needed modeler's participation - J: Present the concept model - P: Attend the presentation	J: Whiteboard A. Then curtain down and projector in the front
3:25	Group modeling	*Structure elicitation* (50 min)	- M: Observe the group and clarify if needed modeler's participation - J: Present the concept model - P: Attend	
4:15	Revision of first result	*Reflector feedback* (10 min)		
4:30	End	Provide deliverable from the session, announce possible future contact and end		

Appendix 2. Fixed order time period model

The "Fixed order time period model" defines that orders must be placed every fixed period of time, in this case every month. Each order includes the sum of two quantities: (a) a quantity required to maintain a safety stock; and (b) the expected sales quantity during the lead-time (the time elapsed from the moment the order is placed to the moment it arrives). Finally from this sum is subtracted the actual inventory plus the inventory in transit. An assumption of this model is that the demand over a period of time has a normal distribution with a mean and a standard deviation. The formula used in the calculation is:

$$Order\ qty = safety\ stock + expected\ demand\ over\ the\ leadtime - effective\ stock + avg\ demand$$

$$q \quad = \quad z\sigma_{T+L} \quad + \quad \bar{d}(T+L) \quad - \quad I \quad + \quad \bar{d}$$

Where:

$T = Time\ between\ reviews$

$L = Lead\ time\ (time\ between\ placing\ an\ order\ and\ receiving\ it)$

$\bar{d} = Forecast\ average\ demand$

$z = Number\ of\ standard\ deviations\ for\ safety\ stock$

$\sigma_{T+L} = Standard\ deviation\ of\ demand\ over\ the\ review\ and\ lead\ time$

$I = Current\ inventory\ level\ plus\ inventory\ in\ transit$

In the case of UMG, the values assigned to each variable are the following:

$T = 1\ month$

$L = 3\ months$

$\bar{d} = Weighted\ average\ demand\ for\ the\ last\ six\ months$

$z = -0.42 ln\left[(1 - DSL) * \frac{\bar{d}}{\sigma_{T+L}}\right] - 0.124$

$\sigma_{T+L} = Standard\ deviation\ of\ the\ demand\ for\ the\ last\ T + L\ months$

$I = Inventory\ on\ hand\ plus\ inventory\ in\ transit$

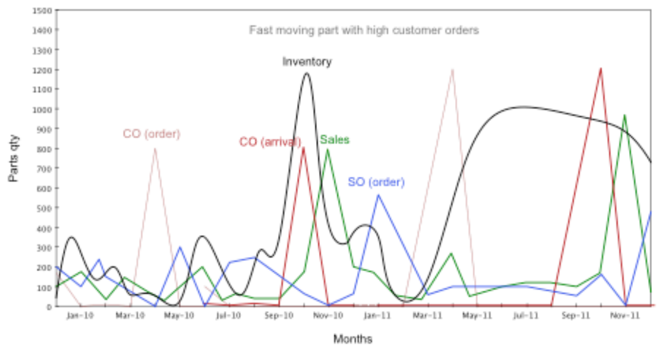
$DSL = Desired\ service\ level = 95\%$

Arguably the most intricate calculation corresponds to the number of standard deviations to keep in safety stock, or z. In the literature, one approach to the calculation of the value of z, called the "probability approach" is related to the desired service level to be provided. If the demand follows a normal distribution with an average demand and standard deviation, then, the cumulative standard normal distribution (CSND) will help to determine how many standard deviations of safety stock are required for a particular service level. For example, moving one standard deviation to the right of the mean of the demand in the CSND will give a probability of 0.8413. Meaning that there is 84% of chance that there will NOT be a stock out keeping a safety stock equal to one standard deviation from the average demand (Jacobs, et al., 2010). Conversely, there is 16% chance that there will be a stock out.

UMG has specified a chance of NOT stocking out of 96%, which would mean based on this method that a safety stock of approx. 1.7 standard deviations should maintained. However, the calculation UMG uses for z is more complex. Given the lack of documentation it is not practical to elucidate the meaning of each of its terms, still, it is possible to foresee that when the standard deviation is bigger than the average demand, the value of z will be higher, increasing the safety stock. In conclusion, the safety stock is higher as the standard deviation from the average demand grows. Such response is similar to that of the models that use the simpler probability approach. Hence, it is plausible to think of UMG's model as an extension of the probability model, where safety stock is calculated as a number of times of the standard deviation of the demand.

Appendix 3. Format used for the good and bad activity

1. Customer orders are dangerous



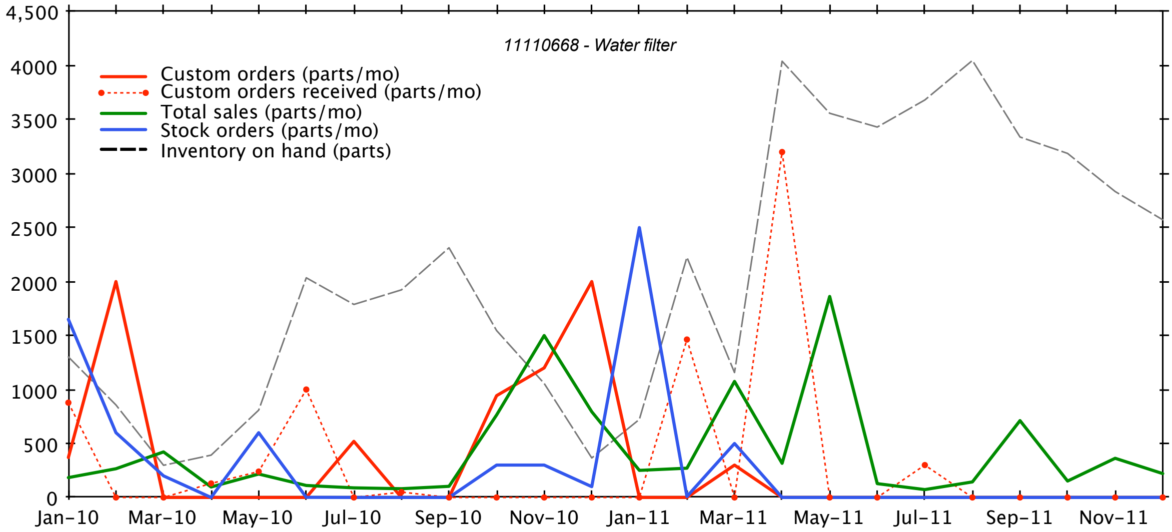
Because orders from UMG to its principals are based on past sales, customer order sales are added to regular stock sales to make new regular stock orders. As a result, stock orders are higher than normal and inventory higher than needed.

Good?

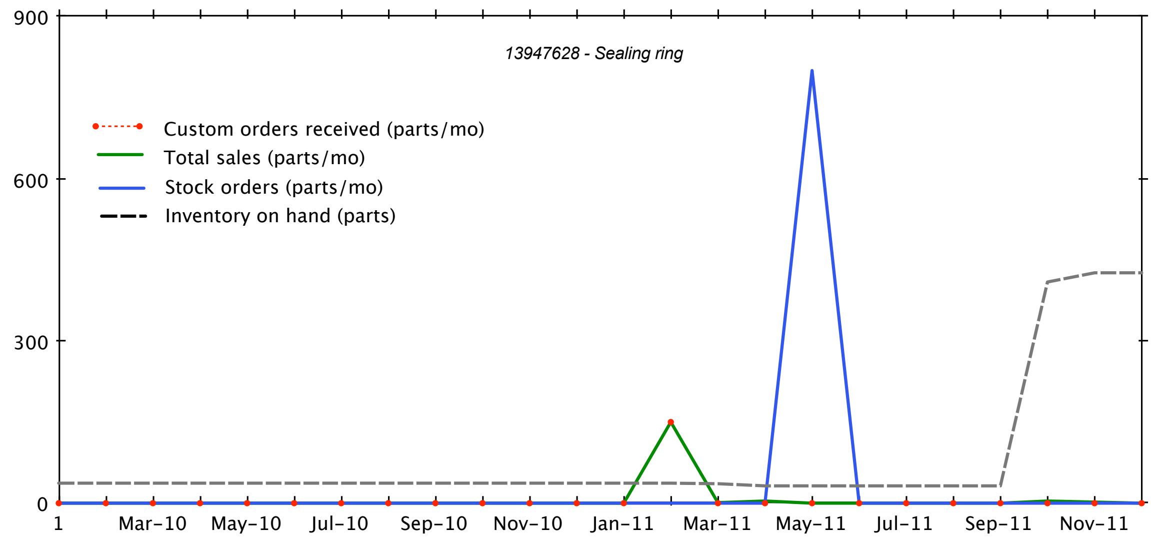
Bad?

Appendix 4. Additional examples of historical behaviors

The following graph presents a case similar to that of scenario 3:



The following graph presents a case similar to that of scenario 4:



Appendix 5. List of equations for the simulation model

The model of the first iteration can also be found here since it is a sub-model of the model built in the second iteration

Name	**Unit**	**Definition**
UMG Order rate SO	part/mo	'Order processing rate SO'
UMG Order rate EO	part/mo	'Order processing rate EO'
UMG Order rate CO	part/mo	'Order processing rate CO'
UMG inventory amplification		('Inventory on hand IOH SO'+'Inventory in transit IIT SO')/'Init UMG inventory'-1
UMG forecasted days		IF (Days+'UMG Forecast length'>=359,Days+'UMG Forecast length'-359,Days+'UMG Forecast length')
UMG Forecast length		2*30
ttp sales	mo	3<<mo>>//-STEP(5<<mo>>,STARTTIME+12<<mo>>)
ttp IOH	mo	2<<mo>>//-STEP(5<<mo>>,STARTTIME+12<<mo>>)
ttp IIT	mo	1<<mo>>
Total sales items proposal IMS	part/mo	GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Sales items proposal IMS')*1<<part/mo>>
Total sales	part/mo	'Delivery rate SO'+'Delivery rate CO'
Total perceived IIT summary	part	('Perceived IIC'+'Perceived IIT'+'Perceived OIP')*'Test IIT awareness'
Total OIP	part	'Orders in process OIP CO'+'Orders in process OIP SO'+'Orders in process OIP EO'
Total IOH	part	'Inventory on hand IOH CO'+'Inventory on hand IOH SO'
Total IITs	part	'Inventory in transit IIT CO'+'Inventory in transit IIT SO'+'Inventory in transit IIT EO'

Total IIT_IIC_OIP	part	'Inventory in customs IIC CO'+'Inventory in customs IIC SO'+'Inventory in transit IIT CO'+'Inventory in transit IIT SO'+'Inventory in transit IIT EO'+'Orders in process OIP CO'+'Orders in process OIP SO'+'Orders in process OIP EO'
Total IIT	part	'Inventory in customs IIC SO'+'Inventory in transit IIT SO'+'Orders in process OIP SO'
Total IIC	part	'Inventory in customs IIC CO'+'Inventory in customs IIC SO'
Time to import	mo	0.5<<mo>>
time to average	mo	12<<mo>>
test zero orders		0
Test SO sales		1
test sinusoidal input		1+SINWAVE(1*0.2,12<<mo>>,'Init policy year'-STARTTIME)
test pulse CO sales		1*(+1*((STEP(1,'Init policy year'))-(STEP(1,'Init policy year'+2<<mo>>))) +1*((STEP(1,'Init policy year'+1<<yr>>))-(STEP(1,'Init policy year'+1<<yr>>+2<<mo>>))) +1*((STEP(1,'Init policy year'+2<<yr>>))-(STEP(1,'Init policy year'+2<<yr>>+2<<mo>>))) +1*((STEP(1,'Init policy year'+3<<yr>>))-(STEP(1,'Init policy year'+3<<yr>>+2<<mo>>))) +1*((STEP(1,'Init policy year'+4<<yr>>))-(STEP(1,'Init policy year'+4<<yr>>+2<<mo>>))))
test lagged orders sales	part/mo	DELAYPPL('Custom orders exogenous input',3<<mo>>)

Test inputs regular orders	part/mo	'regular order reference use'*{Seasonality,'test zero orders','test dramatic rise','test sinusoidal input','test constant sales','ramp increase','Historic SO sales'/'regular order reference use','Historic SO sales'/'regular order reference use',0}
Test inputs custom sales	part/mo	{0<<part/mo>>,-1<<part/mo>>, 'Historic CO sales'}
Test inputs custom orders	part/mo	'custom order reference use'*{'test pulse CO sales','test zero orders','test dramatic rise','test sinusoidal input','test constant sales','ramp increase','Historic custom orders IMS'/'custom order reference use','Historic custom orders IMS'/'custom order reference use'}
Test IIT awareness		1+0*MAX(GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Test IIT awareness'),0)
test dramatic rise		0 +(STEP(0.5,'Init policy year'))
test constant sales		1
test constant CO sales		0 +(STEP(1,'Init policy year'))
Test CO sales		1
Test CO orders		1
Target delivery delay	mo	0.125<<mo>>
Stock order rate	part/mo	IF ('Test SO sales'=8, 'Historic stock orders IMS', MAX(('Adjustment IOH'+'Adjustment IIT'+'Adjustment safety stock'+'Adjustment backlog')/'Inventory adjustment time',0<<part/mo>>))
SO Order processing time	mo	2<<mo>>

Seasonality		GRAPH(Days,0,1,{ 1 , 0.98 , 0.97 , 0.95 , 0.93 , 0.92 , 0.9 , 0.88 , 0.87 , 0.85 , 0.83 , 0.82 , 0.8 , 0.78 , 0.77 , 0.75 , 0.73 , 0.72 , 0.7 , 0.68 , 0.67 , 0.65 , 0.63 , 0.62 , 0.6 , 0.58 , 0.57 , 0.55 , 0.53 , 0.52 , 0.5 , 0.48 , 0.47 , 0.45 , 0.43 , 0.42 , 0.4 , 0.38 , 0.37 , 0.35 , 0.33 , 0.32 , 0.3 , 0.28 , 0.27 , 0.25 , 0.23 , 0.22 , 0.2 , 0.18 , 0.17 , 0.15 , 0.13 , 0.12 , 0.13 , 0.17 , 0.2 , 0.23 , 0.27 , 0.3 , 0.33 , 0.37 , 0.4 , 0.43 , 0.47 , 0.5 , 0.53 , 0.57 , 0.6 , 0.63 , 0.67 , 0.7 , 0.73 , 0.77 , 0.8 , 0.83 , 0.87 , 0.9 , 0.93 , 0.97 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 //Min:0;Max:1//})
Sales rate amplification		'Delivery rate SO'/'Init Sales rate'-1
Result	part/mo	'Total sales items proposal IMS'*Fraction
Reliability of IIT	%	100%

Regular orders input	part/mo	'Test inputs regular orders'[INDEX(INTEGER('Test SO sales'))]
regular order reference use	part/mo	InitialValuesExcel[5]*1<<part/mo>>//5500<<part/mo>>
Regular order rate	part/mo	'Regular orders input'
Rate_3	part/mo	'Stock order rate'+('Custom orders exogenous input'+'Desired order rate EO')*0
Rate_2	part/mo	'Arrival rate'+('Arrival rate CO'+'Import rate EO')*0
Rate_1	part/mo^2	('Total sales items proposal IMS'-'Average sales 101')*2/'time to average'
ramp increase fraction		0+RAMP(1/24<<mo>>,'Init policy year')
ramp increase		1+1*'ramp increase fraction'
Perceived sales test	part/mo	DELAYINF('Total sales items proposal IMS',3<<mo>>,3,1500<<part/mo>>)
Perceived sales	part/mo	DELAYINF('Total sales', 'ttp sales', 3, IF ('Initial stock conditions'=1, 'Regular orders input'+'Custom orders exogenous input', InitialValuesExcel[6]*1<<part/mo>>))
Perceived OIP	part	DELAYINF('Orders in process OIP SO'+'Orders in process OIP CO'*0, 'ttp IIT', 3, IF ('Initial stock conditions'=1, 'Orders in process OIP SO'+'Orders in process OIP CO', InitialValuesExcel[10]*1<<part>>)) * 'Reliability of IIT'
Perceived IOH test	part	DELAYINF('IOH from IMS'-'Inventory on hand IOH CO',16<<mo>>,6,0<<part>>)
Perceived IOH	part	DELAYINF('Inventory on hand IOH SO'+'Inventory on hand IOH CO', 'ttp IOH', 3, IF ('Initial stock conditions'=1, 'Inventory on hand IOH SO'+'Inventory on hand IOH CO', (InitialValuesExcel[8])*1<<part>>))

Perceived IIT from model approx	part	'Test IIT awareness'*DELAYINF('IIT from Model approximation',1<<mo>>,3,8000 <<part>>)
Perceived IIT	part	DELAYINF('Total IIT', 'ttp IIT', 3, IF ('Initial stock conditions'=1, 'Total IIT', InitialValuesExcel[9]*1<<part>>)) * 'Reliability of IIT'
Perceived IIC	part	DELAYINF('Inventory in customs IIC SO'+'Inventory in customs IIC CO'*0, 'ttp IIT', 3, IF ('Initial stock conditions'=1, 'Inventory in customs IIC SO'+'Inventory in customs IIC CO', InitialValuesExcel[11]*1<<part>>)) * 'Reliability of IIT'
Perceived backlog	part	DELAYINF('Order backlog SO','Backlog perception time',1,'Order backlog SO')
Orders in process OIP SO	part	IF ('Initial stock conditions'=1, 'Average sales'*'SO Order processing time', InitialValuesExcel[2]*1<<part>>//73<<parts>>//)
Orders in process OIP EO	part	IF ('Initial stock conditions'=1, 'Custom orders exogenous input'*'Order processing time EO', InitialValuesExcel[19]*1<<part>>)
Orders in process OIP CO	part	IF ('Initial stock conditions'=1, 'Custom orders exogenous input'*'CO Order processing time', InitialValuesExcel[14]*1<<part>>)
Order processing time EO	mo	0.5<<mo>>

Order processing rate SO	part/mo	DELAYMTR('Incoming OIP rate SO','SO Order processing time',6, IF ('Initial stock conditions'=1, 'Incoming OIP rate SO', 'Orders in process OIP SO'/'SO Order processing time'))//'Orders in process OIP SO'/'SO Order processing time'//
Order processing rate EO	part/mo	'Orders in process OIP EO'/'Order processing time EO'
Order processing rate CO	part/mo	DELAYMTR('Incoming OIP rate CO','CO Order processing time',6, IF ('Initial stock conditions'=1, 'Incoming OIP rate CO', 'Orders in process OIP CO'/'CO Order processing time'))//'Orders in process OIP CO'/'CO Order processing time'//
Order fulfillment ratio		GRAPH('Delivery rate adequacy',0,0.1,{0 , 0.1 , 0.2 , 0.3 , 0.35 , 0.4 , 0.45 , 0.5 , 0.55 , 0.6 , 0.65 , 0.68 , 0.71 , 0.74 , 0.77 , 0.8 , 0.83 , 0.86 , 0.89 , 0.92 , 0.95 , 0.98 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 //Min:0;Max:1//})
Order delivery rate SO	part/mo	'Delivery rate SO'
Order delivery rate EO	part/mo	'Delivery rate EO'
Order delivery rate CO	part/mo	'Delivery rate CO'
Order backlog SO	part	IF ('Initial stock conditions'=1, 'Average order input'*('Target delivery delay'), InitialValuesExcel[1]*1<<part>>/ /'Average order rate'*('Target delivery delay')//)
Order backlog EO	part	(IF ('Initial stock conditions'=1, 'Emergency orders input'*1<<mo>>, InitialValuesExcel[18]*1<<part>> //'Average order rate'*('Target delivery delay')//))

Order backlog CO	part	(IF ('Initial stock conditions'=1, 0<<part>>,//'Custom orders input'*1<<mo>>,// InitialValuesExcel[13]*1<<part>> //'Average order rate'*('Target delivery delay')//))
OldDelay	part/mo	DELAYINF('Total sales items proposal IMS',6<<mo>>,3,1000<<part/mo>>)
Normal order backlog	part	'Average order input'*('Target delivery delay')
Minimum order-handling time	mo	0.125<<mo>>
Maximum delivery rate	part/mo	'Inventory on hand IOH SO'/'Minimum order-handling time'
Lost sales	part/mo	MAX('Order backlog SO'/('Customer acceptable delivery delay')-'Order delivery rate SO',0<<part/mo>>)
Level_2	part	0<<part>>
Level_1	part	0<<part>>
IOH SO	part	'Inventory on hand IOH SO'
IOH in proposal	part	GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - IOH in proposal')*1<<part>>
IOH from IMS	part	GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - IOH from IMS')*1<<part>>
IOH CO	part	'Inventory on hand IOH CO'+'Inventory on hand IOH SO'+'Inventory on hand IOH EO'*0+'Dead stock'*0
Inventory turnover	mo^-1	'Average sales'/'Inventory on hand IOH SO'
Inventory on hand IOH SO	part	IF ('Initial stock conditions'=1, ('Desired coverage IOH')*'Average sales', InitialValuesExcel[4]*1<<part>>//50000<<parts>>//)

Inventory on hand IOH EO	part	IF ('Initial stock conditions'=1, 2000<<part>>, InitialValuesExcel[21]*1<<part>>)
Inventory on hand IOH CO	part	IF ('Initial stock conditions'=1, 'Custom orders exogenous input'*'Average CO delivery delay', InitialValuesExcel[17]*1<<part>>)
Inventory in transit IIT SO	part	IF ('Initial stock conditions'=1, 'Average sales'*'Time to import', InitialValuesExcel[3]*1<<part>>/ /11000<<parts>>//)
Inventory in transit IIT EO	part	IF ('Initial stock conditions'=1, 'Custom orders exogenous input'*'Time to import', InitialValuesExcel[20]*1<<part>>)
Inventory in transit IIT CO	part	IF ('Initial stock conditions'=1, 'Custom orders exogenous input'*'Time to import', InitialValuesExcel[15]*1<<part>>)
Inventory in customs IIC SO	part	IF ('Initial stock conditions'=1, 'Average sales'*'Customs clearance time', InitialValuesExcel[7]*1<<part>>/ /11000<<parts>>//)
Inventory in customs IIC CO	part	IF ('Initial stock conditions'=1, 'Custom orders exogenous input'*'Customs clearance time', InitialValuesExcel[16]*1<<part>>)
Inventory adjustment time	mo	1<<mo>>
InputParameters - Total Sales		XLDATA("InputParameters.xlsx", "TimeSeries","G4:G27")
InputParameters - Total orders IMS		XLDATA("InputParameters.xlsx", "TimeSeries","H4:H27")
InputParameters - Total Inventory IMS		XLDATA("InputParameters.xlsx", "TimeSeries","K4:K27")
InputParameters - Test IIT awareness		XLDATA("InputParameters.xlsx", "TimeSeries","L4:L27")

InputParameters - Stock orders proposal		XLDATA("InputParameters.xlsx", "TimeSeries","E4:E27")
InputParameters - Stock orders IMS		XLDATA("InputParameters.xlsx", "TimeSeries","F4:F27")
InputParameters - SO Sales		XLDATA("InputParameters.xlsx", "TimeSeries","C4:C27")
InputParameters - Sales items proposal IMS		XLDATA("InputParameters.xlsx", "SalesInfoDelayTest","C4:C27")
InputParameters - IOH in proposal		XLDATA("InputParameters.xlsx", "SalesInfoDelayTest","N4:N27")
InputParameters - IOH from IMS		XLDATA("InputParameters.xlsx", "SalesInfoDelayTest","M4:M27")
InputParameters - Inventory from SO		XLDATA("InputParameters.xlsx", "TimeSeries","D4:D27")
InputParameters - IIT in proposal		XLDATA("InputParameters.xlsx", "SalesInfoDelayTest","I4:I27")
InputParameters - IIT from Model approximation		XLDATA("InputParameters.xlsx", "SalesInfoDelayTest","H4:H27")
InputParameters - EO sales		XLDATA("InputParameters.xlsx", "TimeSeries","O4:O27")
InputParameters - Emergency orders IMS		XLDATA("InputParameters.xlsx", "TimeSeries","N4:N27")
InputParameters - Custom orders IMS		XLDATA("InputParameters.xlsx", "TimeSeries","I4:I27")
InputParameters - CO_EO sales		XLDATA("InputParameters.xlsx", "TimeSeries","J4:J27")
InputParameters - Avg sales items in proposal		XLDATA("InputParameters.xlsx", "SalesInfoDelayTest","D4:D27")
InitialValuesExcel		XLDATA("InputParameters.xlsx", "InitialValues","C4:C40")
Initial stock conditions		2
Init UMG inventory	part	INIT('Inventory on hand IOH SO')+INIT('Inventory in transit IIT SO')
Init Sales rate	part/mo	INIT('Delivery rate SO')
Init policy year forecasted	mo	'Init policy year'-'customer forecast length'*1<<da>>
Init policy year	mo	DATE(INTEGER(2011),1,1,0,0)
Init import rate	part/mo	INIT('UMG Order rate SO')
Incoming OIP rate SO	part/mo	'Stock order rate'
Incoming OIP rate EO	part/mo	'Desired order rate EO'
Incoming OIP rate CO	part/mo	'Custom orders exogenous input'

Import rate EO	part/mo	'Inventory in transit IIT EO'/'EO import time'
Import rate CO	part/mo	DELAYMTR('UMG Order rate CO','Time to import',6, IF ('Initial stock conditions'=1, 'UMG Order rate CO', 'Inventory in transit IIT CO'/'Time to import'))//'Inventory in transit IIT CO'/'Time to import'//
Import rate amplification		'UMG Order rate SO'/'Init import rate'-1
Import rate	part/mo	DELAYMTR('UMG Order rate SO','Time to import',6, IF ('Initial stock conditions'=1, 'UMG Order rate SO', 'Inventory in transit IIT SO'/'Time to import'))//'Inventory in transit IIT SO'/'Time to import'//
IIT in proposal	part	GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - IIT in proposal')*1<<part>>
IIT from Model approximation	part	GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - IIT from Model approximation')*1<<part>>
Historic total sales	part/mo	GRAPHSTEP(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Total Sales')*1<<part/mo>>
Historic total orders IMS	part/mo	MAX(GRAPHSTEP(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Total orders IMS')*1<<part/mo>>,0<<part/mo>>)
Historic total IOH IMS	part/mo	MAX(GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Total Inventory IMS')*1<<part/mo>>,0<<part/mo>>)

Historic stock orders P	part/mo	MAX(GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Stock orders proposal')*1<<part/mo>>,0<<part/mo>>)
Historic stock orders IMS	part/mo	MAX(GRAPHSTEP(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Stock orders IMS')*1<<part/mo>>,0<<part/mo>>)
Historic SO sales	part/mo	GRAPHSTEP(TIME ,STARTTIME ,1<<mo>>,'InputParameters - SO Sales')*1<<part/mo>>
Historic IOH from SO	part	GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Inventory from SO')*1<<part>>
Historic EO sales	part/mo	MAX(GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - EO sales')*1<<part/mo>>,0<<part/mo>>)
Historic EO IMS	part/mo	MAX(GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Emergency orders IMS')*1<<part/mo>>,0<<part/mo>>)
Historic custom orders IMS	part/mo	MAX(GRAPHSTEP(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Custom orders IMS')*1<<part/mo>>,0<<part/mo>>)
Historic CO sales	part/mo	MAX(GRAPHSTEP(TIME ,STARTTIME ,1<<mo>>,'InputParameters - CO_EO sales')*1<<part/mo>>,0<<part/mo>>)
Fraction		0.375

Forecasted seasonality UMG		GRAPH('UMG forecasted days',0,1,{ 1 , 0.98 , 0.97 , 0.95 , 0.93 , 0.92 , 0.9 , 0.88 , 0.87 , 0.85 , 0.83 , 0.82 , 0.8 , 0.78 , 0.77 , 0.75 , 0.73 , 0.72 , 0.7 , 0.68 , 0.67 , 0.65 , 0.63 , 0.62 , 0.6 , 0.58 , 0.57 , 0.55 , 0.53 , 0.52 , 0.5 , 0.48 , 0.47 , 0.45 , 0.43 , 0.42 , 0.4 , 0.38 , 0.37 , 0.35 , 0.33 , 0.32 , 0.3 , 0.28 , 0.27 , 0.25 , 0.23 , 0.22 , 0.2 , 0.18 , 0.17 , 0.15 , 0.13 , 0.12 , 0.13 , 0.17 , 0.2 , 0.23 , 0.27 , 0.3 , 0.33 , 0.37 , 0.4 , 0.43 , 0.47 , 0.5 , 0.53 , 0.57 , 0.6 , 0.63 , 0.67 , 0.7 , 0.73 , 0.77 , 0.8 , 0.83 , 0.87 , 0.9 , 0.93 , 0.97 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 //Min:0;Max:1//})

Forecasted seasonality customer		GRAPH('customer forecasted days',0,1,{ 1 , 0.98 , 0.97 , 0.95 , 0.93 , 0.92 , 0.9 , 0.88 , 0.87 , 0.85 , 0.83 , 0.82 , 0.8 , 0.78 , 0.77 , 0.75 , 0.73 , 0.72 , 0.7 , 0.68 , 0.67 , 0.65 , 0.63 , 0.62 , 0.6 , 0.58 , 0.57 , 0.55 , 0.53 , 0.52 , 0.5 , 0.48 , 0.47 , 0.45 , 0.43 , 0.42 , 0.4 , 0.38 , 0.37 , 0.35 , 0.33 , 0.32 , 0.3 , 0.28 , 0.27 , 0.25 , 0.23 , 0.22 , 0.2 , 0.18 , 0.17 , 0.15 , 0.13 , 0.12 , 0.13 , 0.17 , 0.2 , 0.23 , 0.27 , 0.3 , 0.33 , 0.37 , 0.4 , 0.43 , 0.47 , 0.5 , 0.53 , 0.57 , 0.6 , 0.63 , 0.67 , 0.7 , 0.73 , 0.77 , 0.8 , 0.83 , 0.87 , 0.9 , 0.93 , 0.97 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 //Min:0;Max:1//})
Expected order lead time EOL	mo	4<<mo>>
EO import time	mo	0.25<<mo>>

Endogenous delivery rate	part/mo	0*DELAYMTR('Arrival rate CO','Average CO delivery delay',12,0<<part/mo>>) +1*'Inventory on hand IOH CO'/'Average CO delivery delay'
Emergency orders input	part/mo	'Historic EO IMS'
Emergency order rate	part/mo	'Emergency orders input'
Desired order rate EO	part/mo	'Emergency orders input'
Desired IOH	part	IF ('Initial stock conditions'=1 AND ('Test SO sales'<>1 AND 'Test SO sales'<>7), 'Desired coverage IOH'*'Average sales', 'Desired coverage IOH'*'Average sales')
Desired IIT	part	IF ('Initial stock conditions'=1 AND ('Test SO sales'<>1 AND 'Test SO sales'<>7), 'Expected order lead time EOL'*'Average sales'*'Reliability of IIT', 'Expected order lead time EOL'*'Average sales'///'Reliability of IIT'//)
Desired delivery rate	part/mo	'Order backlog SO'/'Target delivery delay'
Desired coverage safety stock	mo	1<<mo>>
Desired coverage IOH	mo	1<<mo>>
Delivery rate SO	part/mo	'Desired delivery rate'*'Order fulfillment ratio'
Delivery rate EO	part/mo	IF ('Initial stock conditions'=1, 'Emergency orders input', 'Historic EO sales')
Delivery rate CO	part/mo	IF('Custom sales exogenous input'=0<<part/mo>>,0<<part/mo>>, IF('Custom sales exogenous input'=-1<<part/mo>>, 'Endogenous delivery rate', 'Custom sales exogenous input'))
Delivery rate adequacy		DIVZX('Maximum delivery rate','Desired delivery rate',1)
Delivery delay	mo	'Order backlog SO'/'Order delivery rate SO'
Dead stock	part	0*50000<<part>>

Days		IF(MONTH(TIME)=1,DAY(TIME), DAY(TIME)+(MONTH(TIME)-1)*30)-1
Customs clearance time	mo	1.5<<mo>>
customer forecasted days		IF (Days+'customer forecast length'>=359,Days+'customer forecast length'-359,Days+'customer forecast length')
customer forecast length		5*30
Customer acceptable delivery delay	mo	'Target delivery delay'*1.2
custom sales reference use	part/mo	InitialValuesExcel[12]*1<<part/mo>>//5500<<part/mo>>
Custom sales exogenous input	part/mo	'Test inputs custom sales'[INDEX(INTEGER('Test CO sales'))]
Custom orders exogenous input	part/mo	'Test inputs custom orders'[INDEX(INTEGER('Test CO orders'))]
custom order reference use	part/mo	InitialValuesExcel[12]*1<<part/mo>>//5500<<part/mo>>
Custom order rate	part/mo	'Custom orders exogenous input'
Copy of UMG forecasted days		IF (Days+'Copy of UMG forecast length'>=359,Days+'Copy of UMG forecast length'-359,Days+'Copy of UMG forecast length')
Copy of UMG forecast length		1*30
Copy of Historic EO sales	part/mo	MAX(GRAPHSTEP(TIME ,STARTTIME ,1<<mo>>,'InputParameters - EO sales')*1<<part/mo>>,0<<part/mo>>)
Copy of Historic EO IMS	part/mo	MAX(GRAPHSTEP(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Emergency orders IMS')*1<<part/mo>>,0<<part/mo>>)
Copy of Emergency orders input	part/mo	'Historic EO IMS'
CO Order processing time	mo	2<<mo>>
Backlog perception time	mo	2<<mo>>
Backlog adjustment required	part	('Perceived backlog'-'Normal order backlog')

Avg sales items in proposal	part/mo	GRAPHLINAS(TIME ,STARTTIME ,1<<mo>>,'InputParameters - Avg sales items in proposal')*1<<part/mo>>
Average sales timespan	mo	6<<mo>>
Average sales 101	part/mo	800<<part/mo>>
Average sales	part/mo	DELAYINF('Perceived sales', 'Average sales timespan', 1, IF ('Initial stock conditions'=1, 'Perceived sales', InitialValuesExcel[6]*1<<part/mo>>))
Average order input	part/mo	DELAYINF('Regular orders input',3<<yr>>,3)
Average CO delivery delay	wk	0*6*4<<wk>>//0.5// +0.5*4<<wk>>
Auxiliary_1		PAUSEIF(MONTH()=2 AND FALSE)
Arrival rate CO	part/mo	DELAYMTR('Import rate CO','Customs clearance time',6, IF ('Initial stock conditions'=1, 'Import rate CO', 'Inventory in customs IIC CO'/'Customs clearance time'))//('Inventory in customs IIC CO'/'Customs clearance time')
Arrival rate	part/mo	DELAYMTR('Import rate','Customs clearance time',6, IF ('Initial stock conditions'=1, 'Import rate', 'Inventory in customs IIC SO'/'Customs clearance time'))//('Inventory in customs IIC SO'/'Customs clearance time')
Adjustment safety stock	part	('Average sales'*'Desired coverage safety stock')
Adjustment IOH	part	('Desired IOH'-'Perceived IOH')*1
Adjustment IIT	part	'Desired IIT'-'Perceived IIT'
Adjustment backlog	part	'Backlog adjustment required'