Eindhoven University of Technology

MASTER

On-time shipment & Telone inventory management with spot market options

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Subject headings; On-Time Shipment, Intermediate storage tanks, autonomous supply, Co and By products, spot markets.
PREFACE

This document contains a Master Thesis project finalizing my MSC. Operation Management and Logistics program in Eindhoven University of Technology, sub-department of operations, planning, Accounting and Control. The Master thesis project has been supervised by Dr. H.P.G. van Ooijen and Dr. S.D.F. Flapper. This project has been conducted in cooperation with Dow AgroSciences in supervision of BSc. M. Antheunis.

First of all, I want to present my special thanks to Mario Antheunis, who initiated this project, gave me the opportunity to conduct my graduation project at Dow AgroSciences, providing the required information and sharing this insights and experiences.

From the university, I would like to thank Henny van Ooijen, my first supervisor, for his constructive feedback, support and enthusiasm during this project. I also want to thank my second supervisor Simme Douwe Flapper for never hesitating to help, valuable opinion during this project.

Furthermore, I would like to thank my family and friends for their support during my study. Special thanks to my parents for their support, believe and their continuous encouragement.

Otman Amohammadi,

November 2011.
ABSTRACT

This report includes a project proposal for the Master Thesis project on supply chain management which aims to improve the overall supply chain performance of the Telone products. Two distinctive problem statements are formulated which are the main focus of this project; On-time shipment and the Inventory management. This study also includes an empirical justification; it is tested in collaboration with a company named Dow AgroSciences (DAS).
Managment Summary

The initial aim of this study was to improve the On-Time Shipment performance of Dow AgroSciences (Telone Supply Chain). The On-Time Shipment performance measure of the Telone Supply chain performs under the business standard which indicates that the performance needs to be at least 95%.

After the orientation phase it became clear that the data concerning the On-Time Shipment performance could not be used as the starting point; this because of the lack and trustfulness in the data. This all has changed the direction of the study into evaluating the On-Time Shipment performance measure itself (policy). We have found that the importance of the metric was not evenly distributed over all the involved parties. Dow AgroSciences is the owner of the Telone product but has outsources the production, packaging and some of the (planning and Scheduling activities) to other businesses within Dow (Dow chemical and BPSC). During our interview sessions we have discovered that the employees are not aware of the existence of the On-Time shipment performance measure. The main reason for this was that no agreements were made between Dow AgroSciences and the other parties regarding the level at which the outsourced activities needs to be performed. Therefore, we highly recommend that service agreements needs to be established between Dow AgroSciences and the involved parties. Service agreements needs to establish and enforce the involved parties to commit effort towards the On-Time Shipment performance.

The current On-Time Shipment measurement process does not distinguish the performance of the different measurement points. Because of this, it is difficult to indicate what the contribution is of each measurement point. For this recommend to keep separate On-Time Shipment performance scores for each measurement point. It also became clear that during the failure collection points responsible employees did not remember the causes for specific failures. Therefore, we would like to recommend that each failure in OTS performance needs to be documented at the end of a working day. One major issue of the On-Time Shipment performance measurement process is the lack of an improvement team which needs to address OTS failures. In order to have an effective improvement team which addresses failures, the right participants are needed to be included. For this we would like to add the following representatives; Scheduler drumming line, logistic service coordinator Bulk truck and the logistic service coordinator Bulk railcar to the S&OP supply meeting. At the supply meeting the On-Time Shipment performance will be discussed and failures are needed to be addressed. However, the On-Time Shipment failures for which higher hierarchical management involvement is needed needs to be discussed at the A.I meeting. Failures that are unresolved at the supply meeting needs to be addressed at the A.I meeting. Also for the A.I meeting we would like to recommend to include the site logistic specialist or leader as they take decisions regarding extra resources. Moreover, reviewing the On-Time Shipment performance with the site logistic specialist or leader helps also to inform the specialist or leader about the performance of their employees regarding the On-Shipment.

During the Orientation phase we have discovered that no formal inventory management policies where used within the Telone supply chain. Therefore, next to the initial On-Time Shipment assignment a second study "Inventory management” has been conducted within this report. For the inventory management assignment, the lack of an inventory policy has resulted in production losses at the production stage of the Telone supply chain because of a full (AV-1006) intermediate storage tank.

Because of this a tool has been designed which needs to assist with making decision regarding overseas shipments. This tool consists of a Mixed Integer liner programing (MILP) which uses “OpenSolver” as the software for solving the model. The software uses the excel format for input and output of the MILP model because of this it is easily to modify and to read the outcome results. A user friendly output interface has been designed in excel which enables to analyze the output of the model. We have only included the most important output data from the model into the output interface. This because too much information might loss the focus of the model.
**Results**

The model shows that the overseas shipments could be increased with 25%. Moreover, because of the timing and volumes for the overseas shipments no instances of overflows have been found in the model. The stock-out percentage of the model was 1.4% and is only observed for the Bulk orders within the Europe.
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1) Introduction
This report contains a Master Thesis project that investigates the On-Time Shipment Performance within the process industry. This Master Thesis project is conducted at Dow AgroSciences which offers a wide solution for the agricultural and Biological markets.

Chapter two provides a detailed company description, the Telone product of Dow AgroSciences is introduced. Next to this, the main characteristics of the Telone supply chain is provided. Chapter 3 deals with the problem definition and research approach of this project. A detailed supply chain analysis is provided in chapter 4, this also contains a detailed On-Time Shipment analysis. Chapter 5 includes an evaluation of the On-Time Shipment performance measurement process of the Telone supply chain. At this point recommendations are provided that indicate how to redesign the On-Time Shipment of Dow AgroSciences.

During the orientation phase of this project we also have discovered that Dow AgroSciences had no inventory management policy for the intermediate storage tanks used within the Telone supply chain. For this we also have started a second project called “Inventory management project”. This project starts in chapter 6 where the problem definition and research assignment of the project are explained. Chapter 7 contains a conceptual mathematical model designed for this project. Then, chapter 8 discusses the verification and validation of the mathematical model. Chapter 9 discusses scenario analysis that is conducted with the mathematical model. Whereas, chapter 10 discusses the software implementation phase of the model. Insights obtained from the sensitivity and scenarios analysis are discussed in chapter 11.
2) Company description
In this part an introduction will be provided regarding the company involved in this project. First of all an introduction about Dow Chemical is given, then Dow AgroSciences is discussed. Next to this, the product portfolio of Dow AgroSciences is discussed where the main emphasize is put on the Telone products. Then the organization of the Telone supply chain is portrayed. At last, a description is provided regarding legislation that currently impacts the Telone supply chain.

2.1) Dow chemical
Dow is a diversified chemical company that combines the power of science and technology with the “Human Elements” to constantly improve what is essential to human progress. The company delivers a broad range of products and services to customers in approximately 160 countries, connecting chemistry and innovation with principles of sustainability to help provide everything from fresh water, food and pharmaceutics to paints, packaging and personal care products. In total Dow produces more than 3500 products which bring annual sales of $ 46 billion. Dow’s operational segments include; Advanced materials, Health & Agricultural Sciences, Performance Products & Systems, and Basics.

2.2) Dow AgroSciences

Mission
To constantly improve what is essential to human progress by mastering science and technology.

Manufacturing sites
Dow AgroSciences makes use of about 43 manufacturing sites which are located throughout the world. Many of these manufacturing sites are co-operated by Dow and Dow AgroSciences employees. Next to this, as is depicted in figure 1these sites could either be owned by Dow, Dow AgroSciences or could be a joint venture with other companies.

Figure 1; Dow AgroSciences manufacturing sites.
**Product portfolios**

Dow AgroSciences offers a wide range of solutions for the agricultural and Biological market segments. The product portfolios that belong to the agricultural segment are; fumigants, insecticides, fungicides and the Herbicides. For the agricultural segments, crop protection chemicals including herbicides, insecticides, fumigants and fungicides are produced. A diverse portfolio of herbicides provides weed management for production crops. This helps farmers increasing their yields by reducing weed competition in their crops. A wide range of insecticides is provided to help customers in more than 100 agricultural markets around the world. These products protect crops such as corn and cotton, as well as a variety of fruits and vegetables from insects which can destroy yield. The fungicides provide plant disease management by controlling pathogens in vegetables, fruits, vines, field, and specialty crops. The Fumigants make it possible to prevent insect damage in certain crops before and after they are harvested.

Next to this, Dow AgroSciences offers biological solutions for crop production improvements. The following product portfolios belong to this segment; Seeds & Traits and healthy oils.

**Telone**

Telone soil fumigant is one of the products which belong to the Fumigants portfolio. Telone soil fumigant controls all major species of nematodes, including root knot, reniform, lesion, stubby root, dagger, ring, pin, and cyst nematodes. Telone is injected into the soil as a liquid and immediately converts to a gas, creating a zone of protection around developing roots. Telone also moves throughout the soil on its own, rather than requiring any means of transportation like water. Telone is commonly used on a number of crops including:

- Vegetables including potatoes, melons, tomatoes, peppers, Cole crops and strawberries;
- Field crops, such as cotton, peanuts and tobacco;
- Fruit and nut trees;
- Grapes;
- Nursery Crops.

The Telone product portfolio includes the following products for crop protection for farmers; Telone II, Telone EC, Telone C-17, Telone C-35, and In Line.

**Telone Manufacturing sites**

Next to this, there are two Manufacturing sites which are used to produce Telone products; Freeport (U.S.A) and Stade (Germany). The Manufacturing plant in “Freeport” is supplying Telone products mainly Southern and Northern American trade areas of the world. The “Stade” Manufacturing plant supplies the so called EMEA regions of the world; Europe, Middle East and Africa.
2.3) Organization structure

These Telone Manufacturing sides are both owned by Dow Chemical, which means that the assets and resources that are used for production and packaging (loading stations and drumming lines) are owned by Dow Chemical. The supply chain activities (strategic and tactical levels) are still performed by Dow AgroSciences, whereas the scheduling tasks are either done by Dow AgroSciences or by the Business Process Service Centre (BPSC) which is an independent service provider that is specialized in providing logistical and transactional services to Dow Businesses.

Table 1; Organization structure

<table>
<thead>
<tr>
<th>Telone Activities</th>
<th>Production</th>
<th>Site logistics</th>
<th>Supply chain</th>
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<tbody>
<tr>
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<td>Strategic/tactical</td>
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<td>Performed by</td>
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<td>Chemical</td>
<td>Chemical</td>
<td>AgroSciences</td>
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<td>BPSC &amp; Dow</td>
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<td>Chemical</td>
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Figure 2 illustrates the organogram of the Dow Chemical organization concerning the Telone supply chain of the Stade manufacturing plant.

Figure 2; Organogram.

Legislation

As from 1 September 2008, a new legislative framework Regulation (EC) No 396/2005 of the European Parliament and of the Council on pesticide residues is active. Pesticides are used to protect crops before and after harvest from infestation by pests and plant diseases. A possible consequence of their use may be the presence of pesticide residues in the treated products. It is necessary to ensure that such residues should not be found in food or feed at levels presenting an unacceptable risk to humans. Maximum residue levels (MRLs) are
therefore set by the European Commission to protect consumers from exposure to unacceptable levels of pesticides residues in food and feed. This Regulation completes the harmonization and simplification of pesticide MRLs, whilst ensuring better consumer protection throughout the EU. With the new rules, MRLs undergo a common EU assessment to make sure that all classes of consumers, including the vulnerable ones, like babies and children, are sufficiently protected. All decision-making in this area has to be science-based and a consumer intake assessment has to be carried out by the European Food Safety Authority before concluding on the safety of an MRL.

This new Legislation has impacted the Telone demand and the pattern within Europe. For some countries Dow AgroSciences does not have any permission to sell its Telone products anymore. However, some countries within Europe are granting Dow AgroSciences the so called “emergency usage” permission. This means that Dow AgroSciences can still sell Telone material for 120 days. After this period, Dow AgroSciences is then starting the whole process again to apply for emergence usage permission from each country.

Production & demand
From a global point of view, there is more demand than supply regarding the Telone products. This imbalance is mainly caused by the North, South American and the Pacific trade areas where the demand for Telone products is very high. However, this does not hold for the Northern and Southern European trade markets where new legislations for selling Telone products has impacted the demand within these trade areas. For the remaining trading areas in the world the demand for Telone products is more or less stable.

2.4) Characteristics Telone supply chain
In order to explain the main characteristics of the Telone supply chain we have included a “simplified overview” in figure 3 of the Telone supply chain. This simplified overview does not contain all the details of the process flow. A more detailed overview of the Telone supply chain will be presented at the detailed analysis of the Telone Supply chain.

Figure 3; Telone supply chain
The process flow of the Telone supply chain in figure 3 starts with the suppliers (before the dotted vertical line) which are supplying the Telone process unit with raw materials. Both suppliers are supplying their raw material according an autonomous principle which means that it is not possible for Dow AgroSciences to refuse any delivery of raw materials from these suppliers. The next step is to either process the raw material in the Telone process unit or to burn the raw materials at the burning unit. Both the suppliers and the Telone process unit itself operate according to a continuous mode, which means that there is production 24 hours a day and 7 days in a week. Once we have converted the raw materials into Telone products we can start to pack Telone products into different packaging sizes and ship it to either local warehouses nearby the customers or to the customers directly. There is also an option to separate the output of Telone process unit into Trans and Cis products, these products are demanded by other Dow plants elsewhere around the world. After separating the Telone unit’s output or part of it, we obtain simultaneously Cis and Trans products. These finished materials are then stored in the limited storage tanks (AV422 A, B; the small tanks after the separation unit).

Figure 3, also shows a couple of On-Time Shipment (OTS) measurement points where the shipment dates of orders are measured and later on compared with the planned shipment dates.

The Telone supply chain operates under two different process modes, which means that there is a Customer Order Decouple Point at the storage Tank (AV-1006) and an Order Decouple point at the Local warehouses. All processes before the Customer Order Decouple Points are forecast driven and the processes after the Customer Order Decouple point are order driven.

As it is general known in process industries expensive process units are used for production and are utilized as much as possible. These process units are characterized by their limited flexibility to produce multiple products and the objective is to run at full capacity such to utilize these expensive assets. Next to this, these process units are also limited by a maximum production capacity.

From figure 3, both the suppliers and Telone process units are both processing a single product continuously at a high production rate. For these process units no changeovers or setups are needed since they only produce a single product. Next to this, figure 3 also displays the intermediate storage tanks AV-1008 and AV-1006 that are within the Telone supply chain. The AV-1008 is an intermediate storage tank which balances parts of the supply process and the production process. The AV-1006 storage tank balances the demand and/or packaging process and the production process. However balancing these two consecutive processes has a limit. For example, if the AV-1006 is full it directly influences the throughput of the Telone process unit. This could result in a (partial) blocking effect of the preceding process stages. Blocking occurs when a factory has insufficient inventory space to store produced goods. When there is no space left to store goods the preceding process stage might be forced to either reduce its throughput or shut down completely. However, reducing the throughput of the Telone process unit without burning the material has also a limit this because of the autonomous supply process. It is not possible to refuse or reduce any supply from the suppliers because this means that they need to burn the produced raw material. The burning costs in these situations are later on charged on Dow AgroSciences. In total there are 2 burning options within the Telone supply chain, one option is to burn the raw material obtained from Allyl before processing it at the Telone process unit. The second option is to burn processed raw material which is produced by the Telone process unit.
3) Problem definition and research approach
In this chapter the problem at hand together with the research approach will be provided. First of all background information regarding this project will be provided. Then a short problem analysis will be given, whereas chapter 4 provides a thorough problem analysis. The following subsection includes the research question, a literature review summary, research assignment and finally the scope of the project.

3.1) Problem definition
In this part we will explain the background of this project, the reason why to hire a master student from Technical university of Eindhoven is explained. One of Dow AgroSciences products is suffering from a low supply chain performance. More specifically, the On Time performance of the Telone supply chain in Stade was in 2010 on average 62%. This performance is below the predetermined business service standard which indicates that the OTS performance measure needs to be at least 95%. Also, no differentiation is made between orders that are shipped to early and orders that are shipped to late. Lateness and earliness count both as a miss in the OTS performance. In order to achieve a MRP II “A class” certification the On-Time shipment performance needs to be considered as important; an A class certification demands an OTS performance of at least 95%. The successful implementation of MRP II and achieving Class A performance levels is considered critical to the success of serving customers. Based on the initial background of the problem provided by the management of Dow AgroSciences and the observations during the orientation phase more knowledge has been obtained regarding the problem at hand.

From the available data concerning OTS performance almost 60% of the OTS failures are not supported by a description regarding the cause for the failure. Moreover, from the interviews that were conducted with employees responsible for particular processes (drumming, loading stations etc.), we have found that they could not agree on the remaining percentage of the reported OTS failure for which there was a cause reported. From this line of reasoning, one could question the robustness of the information regarding the OTS performance.

3.2) OTS literature review summary
Before proceeding with the research assignment the available literature concerning performance measurement has been reviewed and will be presented in this subsection. Instead of providing a detailed literature review, this part only concerns a summary of relevant articles found in literature. For the full literature review study we refer to O. Amohammadi (2011).

M. Bourne et al (2000) addresses issues that are faced during the designing, implementation, usage and the continuously updating performance measurement systems in manufacturing companies. This paper is proposing a framework for analysing the implementation of performance measurement systems. They conclude that specific processes are needed to continuously align the performance measurement system with strategy and that the measurement system needs to include the strategic management process by challenging the strategy itself. The article of M. Bourne (2002), investigated the success and failure of performance measurement system design in ten companies. Both of these articles have discussed performance metric from the system perspective where multiple performance measures are included. However our study only includes a single performance measure instead of a set of performance measures. C. Caplice and Y. Sheffi (1994) proposing a method with which to evaluate existing performance metrics. The article addresses this by suggesting a set of evaluation criteria’s for individual performance metrics.

The article of A. Neely et al (1997) addresses the question of how should specific measures of performance be designed. This paper also proposes a set of criteria’s that can be used to assess whether a performance measure is well-designed or not. The end result is a record sheet which can be used to assess whether a performance measure
measure is “good”. In total they have selected 22 recommendations from literature which indicate what a good performance measure needs to be.

M. Barratt (2004) discusses a couple of points which one needs to understand deeply in order to maximize the success of collaboration. The following questions are extensively discussed in their article; why do we need to collaborate in the supply chain, over what activities do we need to collaborate in the supply chain and at the end the important elements of collaboration. This paper points out the major elements of supply chain collaboration, and points out that many of these elements could be both an enabler and a barrier. Although there are organizations that have integrated various internal departments, marketing and logistics and manufacturing, they still miss a joint goal, shared resources, and common vision that are supporting the collaborative view.

Furthermore the article of M. Barratt (2004) is also pointing out that collaboration is not just about developing close information exchange based on the relationship at an operational level. In order to achieve the full benefit of collaboration it could be necessary to also have implemented collaboration on the tactical and strategic levels in the supply chain. Next also a couple of elements are stated which needs to happen if collaboration is to succeed. These elements are cross functional activities, process alignment, joint decision making and true supply chain metrics. Next to this, a couple strategic elements are needed in order to sustain a collaboration, these elements are; resources and commitment, intra-organizational support, the corporative focus, demonstrating the business case, and the role of technology. Barratt and Oliveira (2001) found that a major barrier to the development of collaboration was the lack of front end agreements as to specifically what organizations were going to collaborate over. Furthermore, because of the e-business which is seen as the key enabler of collaboration such front end agreements are missing.

To conclude, extensive literature is available regarding criteria’s for assessing performance measures in isolation or when it is part of a performance measure system. The missing parts when it comes to the performance measure criteria’s is that no attempt has been made in literature to address performance measures when multiple parties are involved. However, some papers address important aspects within a collaborative supply chain regarding collaboration and the need for this at different hierarchical levels.

3.3) OTS research assignment

Dow AgroSciences is suffering from a low OTS performance of the Telone Supply chain. However during our orientation phase we have discovered that the current OTS performance data is not robust. Because of this the importance of this project has been putted on improving the OTS performance measurement process (policy), such that robust data regarding the OTS performance is created from which corrective actions can be taken.

For this the following research assignment has been formulated;

Redesign the current On-Time Shipment performance measurement process (policy) by taking into consideration the characteristics of a process industry company that is cooperating with different parties.

This redesign of the current On-Time shipment performance measurement process (policy) will be executed by using criteria’s from literature that indicate what a good performance needs to look like. This redesign involves different hierarchical levels as we evaluate the total OTS performance measurement process. The benefit of evaluating the OTS performance measurement process instead of addressing the OTS (reported) misses, is because of the continuously performance improvement logic. Once we have a proper OTS performance measurement process in place, continuous improvement regarding the OTS failure is created. Moreover, a better control and transparency over the Telone processes regarding the OTS performance is also created. Redesigning the OTS performance measure is also only possible if we include the roles that other parties have
(Dow Chemical, BPSC and the logistic service providers (LSP)) as they play a crucial role when it comes to the OTS performance of the Telone supply chain.

3.4) OTS project Scope
In literature a lot of studies have been conducted regarding performance measures, the aim is not to introduce new performance measures or to evaluate the total performance measure system. Instead, a single performance measure is evaluated. According to the article of M. Bourne and J. Mills (2000) the development of a performance measure system can be divided into four main phases (see figure 4);

1. The design of the performance measures;
2. The implementation of the performance measures;
3. The use of the performance measures;
4. Challenging the strategic assumptions.

The design phase can be subdivided into identifying key objectives to be measured and designing the measures themselves. There is a strong consensus amongst authors that measures should be derived from strategy. Implementation is defined as the phase in which the systems and procedures are put in place to collect and process the data that enable the measurements to be made regularly. The use of the performance measure is split into two main categories. First, as the measures are derived from strategy, the initial use to which they should be put is that of measuring the success of the implementation of that strategy. Secondly, the information and feedback from the measures should be used to challenge the assumptions and test the validity of the strategy. At the end there is a reflection of the total performance measurement system regarding the objective of the performance measurement system.

Figure 4; Performance measure system.

Source: Bourne and Mills, 2000
This study mainly concerns the usage of the performance measure (measure, review and act) part of figure 4. Next to this, we would also include the target and the measurement review processes (see the red lines) of the model proposed by M. Bourne and J. Mills (2000).

3.5) OTS research approach
First of all this project starts with general information regarding the problem background, this also includes a company description. Then chapter 3 provides the problem definition, the OTS literature summary, OTS research assignment and the scope. Then in the conceptualization phase a detailed description is provided in chapter 4, this also involves a detailed description of the OTS performance measurement procedure. Then chapter 5 provides the evaluation criteria for a proper performance measures. From this evaluation, recommendations have been provided which indicate how to change the current OTS performance measure process.
4) Supply chain Analysis
In this chapter we will discuss the Telone supply chain of the Telone Manufacturing site in Stade. First of all subsection 4.1 starts explaining the supply chain process of Dow AgroSciences in Stade. Secondly, the supply chain coordination is discussed. At the end, the performance measures of the Telone supply chain are explained and discussed.

4.1) Supply chain process
Figure 5 shows a detailed overview of the Telone Supply chain process of Dow AgroSciences in Stade. This process flow is compared to figure 3 a more detailed version where all processes which might be relevant for this project are incorporated. The process flow of the Telone supply chain will be discussed according the following parts; suppliers, AV-1008, AV-410, Telone production unit, burning units, Cis-Trans separation process, AV-1006, packaging process and the loading station.

**Suppliers**
The Telone supply chain process starts with the supply of Crude Telone from two distinctive suppliers, the internal and external supplier.

**Internal Supplier**
The “Allyl production unit” is located at the Stade Manufacturing plant where the Telone process unit is also located. This production unit and the Telone production unit are both owned by Dow chemical. During the production of AllylChloride at the Allyl production unit crude Telone is obtained as a by-product. The Allyl
process unit produces AllylChloride continuously around the clock; this also means that there is a continuous flow of Crude Telone. This Crude Telone is used as raw material for the Telone production process. The Crude Telone that is produced at the Allyl production unit is directly transported by means of pipelines to the AV-410 before it is pushed into Telone process unit. However as figure 5 shows it is also possible to push the Crude Telone obtained from Allyl into the AV-1008 storage tank during unusual circumstances.

External supplier
Next to the flow of Crude Telone that is obtained from the Allyl production unit there is also a second supplier “Momentive” which supplies Crude Telone to the Telone process unit. The external supplier Momentive is located in Rotterdam (The Netherlands). In order to transport Crude Telone from Momentive to Stade railcars are used. There are in total 10 railcars used for transportation in between Momentive and Stade plant. Once the Crude Telone arrives at the Stade plant it is unloaded in the AV-1008 whenever there is storage capacity available.

AV-1008
The AV-1008 storage tank has a maximum storage capacity of 600 MT. It is only allowed to store at a maximum 240 MT of crude Telone from the Momentive supply in the AV-1008 storage tank. The remaining storage capacity needs to be reserved for the Crude Telone obtained from the Allyl production unit in unusual circumstances. In this case we refer to downstream blocking, machine failure as unusual circumstances.

Burning unit 1
The Crude Telone that is pushed into the Telone process unit cannot be processed anymore under these circumstances, therefore this backup plan is in place. Alongside to this, if these circumstances hold long enough the storage space in AV-1008 that is kept free it won’t be enough. The only option then is to burn the Crude Telone from Allyl at the burning unit depicted in figure 5. The average throughput of Crude Telone from Momentive to the Telone Supply chain is about 3 MT/ per hour, on average the storage space at the AV-1008 will only be enough for approximately 5 days.

However, as one may notice when you wait long enough the same problem will occur at the Momentive plant. Because of this Dow AgroSciences has a backup plan for this which is depicted in figure 5; grey dotted lines between Momentive and the Crude Telone tank in Stade. This second logistical option implies that a storage tank near Momentive owned by Dow is used to buffer the Crude Telone produced by Momentive under these circumstances. Again, from figure 5 we also can see that Momentive also will burn the Crude Telone when their produced raw materials are not taken off. The burning costs for both suppliers will be charged on Dow AgroSciences as they violate the contracts. Again, for the Crude Telone obtained from Momentive it is possible to stock the Crude Telone Material for approximately 8 days in the AV-1008 storage tank. Then if the unusual circumstances still hold on, it is possible to store the Crude Telone for approximately 30 days.

AV-410
The AV-410 tank is a very small buffer which is used to get the right mix of crude Telone obtained from the internal supplier and external supplier before processing it. In essence these raw materials are similar, however the Crude Telone obtained from the external supplier contains a high level of water which causes on the long term corrosion to the pipelines and the equipment used for the processing Telone. Therefore, next to the inflow of Crude Telone from Allyl it is only allowable to have an outflow of at most 40% Crude Telone from Momentive at AV-410 Tank.

The objective of the Manufacturing plant is to keep the throughput of the Telone process unit as high as possible, this in order to increase the Telone process unit utilization. In order to maximize the utilization and throughput of the Telone process unit, a part of the Allyl Crude supply extra Crude Telone is pulled out of the
AV-1008 storage tank and is fed into the AV-410. This happens in consideration of the quality consideration mentioned earlier.

**Telone production unit**
From figure 5 it is clear that the AV-410 is supplying the Telone process unit with Crude Telone, this Crude Telone is then processed into 1.3-DCPE (Dichloropropene). The first step within this production unit is the chlorination process. Then there is a heavy removal process where the heavy parts are extracted and sent to the burning unit. The last step is the removal of the Lights parts, these materials are sent to the Solvent production unit. However because of the domination of the 1.3-DCPE over the Lights no considerations are taken for the Lights during production. The remaining material after the heavy and light separations is the so-called 1.3 DCPE. The Telone process unit is capacitated and can only handle a maximal inflow of Crude Telone from the AV-410. The 1.3 DCPE material is sent to the Cis-trans separation unit or/and to the AV-412.

**Cis-Trans production unit**
The Cis-Trans separation unit is used for to separation 1.3 DCPE materials into Cis and Trans intermediate products. This separation unit can only handle a maximum inflow of 8 MT a day and is used about 30% of its available capacity. Whenever the separation unit is started we both simultaneously produce Cis and Trans intermediate products. If there is only demand for the Cis products then the produced Trans volumes are recycled and pushed back to the AV-410, the same logic holds for the produced Cis volumes. Next to this, when there is demand for the Trans products the logic is to fill the Storage tank AV-422. This is because of the demand pattern for the Trans which are higher than the Cis products. Therefore, the Cis-Trans separation unit will produce exactly the Cis demand when there is no Trans demand.

**AV-1006 (Finished Telone II)**
1.3 DCPE material is mainly transported to the AV-1006 storage tank by means of pipelines, during this process ESO (Epoxidized Soybean Oil) is added to the 1.3 DCPE material. From this blending process Finished Telone II product is obtained. The AV-1006 can maximally store 1000 MT of Finished Telone II products. The Telone II product either supplied the packaging department or the loading station, again the AV-1006 is connected to these successive processes by pipelines.

**Packaging**
Once we have Finished Telone II in the AV-1008 storage tank it is then possible to pack this in different drumming sizes (50/60/200 litres). The packaged drumming orders are first shipped to a warehouse (Pape) nearby Stade. The shipment to Pape is executed on a daily basis by a truck owned by Dow. The warehouse in Pape is used to transfer the drumming orders to the logistical service providers which are transporting the drumming orders either directly to customers (make to order) or to a local warehouse first before it arrives at customers (make to stock). No stock is kept at the Warehouse in Pape, thus it can be seen as an intermediate stop where there is a transfer of drumming orders to the logistical service provider.

The Telone supply chain is operating with two different logistical service providers which transport Telone II to the customers or warehouses. The logistic service provider for the drumming orders is Geodis.

The drumming station that is used for Telone II finished material shares its pallatization process with another drumming line. This means that only one drumming line can use the pallatization process at each drumming run. Next to this, the Telone drumming line also shares labor power with other drumming lines within the packaging department.
Loading stations
Next to the drumming orders it could also be possible that the Telone II orders are shipped in bulk trucks or railcars to the customers directly as is depicted in figure 5. In total there are 3 types of bulk shipments to customers; ISO containers, bulk trucks and railcar bulk.

The CIS and Trans intermediate products are shipped in ISO containers that are loaded on railcars or on trucks. ISO containers on railcars are transported to Rotterdam so that they can be shipped by a vessel to the customers overseas. The ISO containers that are loaded on trucks are transported to customers within Europe.

All the bulk orders that are transported by truck are performed by the logistical service provider “Bertschi”. The railcars which are used for the SIC and Trans intermediates are owned by Dow AgroSciences themselves. The loading station, which is used to load the Telone II, SIC and Trans product on trucks and railcars have a dedicated loading station for Telone material. However, the labor needed for the loading operations are not dedicated instead it is shared with other businesses of Dow in Stade.

Botlek tank
As is mentioned earlier, because of the global demand and production imbalance it is ideally for the Telone supply chain of Stade to ship Telone II to the overseas Trade Markets. In order to ship the Telone II products to the overseas trade markets it is first stored at the storage tank in Botlek. From this point on the Telone II materials are loaded into the reserved capacity within a vessel. However, the selling price for the finished Telone II within the overseas markets is much lower than the selling price within the EMEA trade markets.

4.2) Supply chain Coordination
MRP II is all about matching customer demand with the supply of products they want to buy. As a component of DAS’ strategic roadmap, the successful implementation of MRP II and achieving Class A performance levels is considered critical to the success of the company.

Class A is our ability to have sustained performance based on defined metrics. A couple of metrics are defined along the value chain and include Forecast accuracy and bias continuously improving master production schedule, Produce to plan performance, Inventory record accuracy, And On-Time Delivery to customers.

MRP II consists of two main aspects that drive organizations; demand and supply. Next to this, MRP II also contains a couple of work processes which ensure the financial integration across the entire process. However, these two processes demand and supply are controlled by the management process see appendix A2.
Management contains the sales and operations planning process or S&OP and is DAS' leadership planning and control process for running the business. It begins with demand planning at the RCU level, Translates to the GBU level, and continues through to the final aggregated company plan which is approved at the Executive Sales and Operations Planning meeting. The S&OP process encompasses all plans including sales, production, inventory, new product introductions and financial and provides information for the current year as well as the expectations for the next two years.

**S&OP**

The Sales and Operations Planning process (S&OP) is the coordination and planning process of Dow AgroSciences on a tactical level. It begins with the Sales & Operations Planning at the regional Commercial Unit (RCU) level; this is then translated to the Global Business Unit (GBU) level and continues through to the final aggregated company plan that is approved at the Executive Sales and Operations Planning meeting. The S&OP process includes all plans (sales forecast, production plans, inventory plans, new product instructions and financial plans) and covers a current plus 2 year time horizon.

The Global S&OP process is conducted as a monthly cycle; it starts at the Regional Commercial Unit level, rolls up to the Global Business Unit level and finally to the overall executive DAS level.

The RCUs are focusing on a customers and GMIDs level. The Marketing specialist and/or Sales leaders create the Sales forecast as a part of the RCU S&OP cycle. At the GBU level the focus is more on molecules and assets. The GBU S&OP make decisions on issues that are escalated by the RCU. The focus of the Executive S&OP is on priorities and resources. It sets annual targets, approvals overall financial and operational plans and resolves escalated cross RCU and cross GBU issues. For a full overview of the S&OP cycles see appendix A1.

4.3) Detailed analysis OTS performance

In this section we will discuss the On-Time Shipment performance measure within the Telone supply chain. In this part we will explain the OTS performance metric. Then the performance formula will be explained. After this the point over which the OTS performance is measured and the measurement process will be handled. Then the OTS performance of the year 2010 will be discussed.
On-Time Shipment metric

The On-time Shipment performance measure is based on the differences of the actual customer orders shipment dates and the planned shipment dates. Orders that are shipped too early than the planned shipment date indicates are counted as OTS earliness failures. Orders that are shipped later than the planned shipment dates are counted as OTS lateness failures. The planned shipment date is determined once an order is accepted; SAP will generate the planned shipment dates of each accepted order by using predetermined lead-time structures. The objective and service standard of the business is to have an average On-Time Shipment performance level of at least 95%.

On-Time Shipment Performance measure formula

First we would like to provide the performance measure metrics formula which is used to measure this particular performance. Basically, the On-time Shipment performance measure is based on the differences of the actual shipment date and the planned shipment date. The formula below indicates the ratio between the total number of orders shipped on time and the total number of orders shipped. As the formula shows the OTS performance does not include lost sales because only actual shipments are considered.

\[
\text{On time shipping performance (\%)} = \frac{\text{Total number of orders shipped on time}}{\text{total number of Orders shipped}} \times 100
\]

OTS measurement points

In total there are three measurement points within the Telone supply chain over which the OTS performance is measured. One of the measurement points is the Pape warehouse which is the extension of the drumming line and where drumming orders are stored before transportation (see figure 2). This warehouse is not used to store MTS orders; instead it functions as an intermediate stop before the LSP take the orders to the customers. In order to ship the drumming orders to the Pape warehouse one truck is used for transportation. The distance between the Drumming line at Stade and the Pape warehouse is about 2 km.

The scheduling process of the drumming line is performed by scheduler from the site logistics department at Stade. Next to this, shipments to the Pape warehouse are also coordinated by the drumming scheduler. It is also the task of the scheduler to ship the drumming orders on time to the Pape warehouse. The Drumming station is part of the logistic site department of the Dow Chemical business.

There are also two measurement points for the loading stations “bulk trucks” and “bulk railcar” customer orders. Figure 5 indicates over which products the OTS performance is measured, this includes the drumming orders at the Pape warehouse, Telone Truck, Telone railcar and the Cis and Trans customer orders that are loaded at the loading stations.

These loading stations are dedicated to the Telone products, this because Telone material is considered as hazard content which needs to be treaded carefully (no contamination with other products). Operators that run these loading stations are not dedicated to the Telone loading stations instead the serve multiple loading stations within the Stade plant. Next to the drumming line, the loading stations are also part of the site logistic department of Dow Chemical. The scheduling tasks of the Telone bulk orders that are loaded on trucks are performed by the logistical service coordinator which is located at the BPSC. The scheduling tasks of the Telone bulk orders that are loaded on railcars are performed by the logistical service coordinator from the site logistics department at Stade.
**Performance measurement process**

Every week the project implementation leader collects data from SAP this includes the planned shipment dates and the actual shipment dates. Because of this, the OTS performance of the Drumming, bulk for trucks and railcars is determined. Then the implementation leader needs to attach to each failure a cause of the failure. The implementation leader organizes the OTS performance and the causes of the failures into a format.

The planned and actual shipment dates for each order are extracted from SAP. From these two dates the delays and earliness in shipment dates are determined. From our data analysis we also have found that no distinction is made between MTO and MTS orders. Moreover, there are no specific reason for combining these two types of orders in the OTS performance measurement process. One could argue that it is more important to deal with MTO orders as this influences the customers directly. Another remarkable point is that all orders (drumming, truck bulk and railcar bulk) are not separated from each other instead they are combined into one format (OTS performance format). Next to this, the focus is also on the number of failures and not on the length of the delay or earliness. However, considerable information could be obtained when also reviewing the length of the delays.

Then, from the collected data the OTS performance is calculated. This performance value represents the total OTS performance of all the measurement points within the Telone supply chain.

The next step is to collect for each failure a cause, this process is performed every week by the implementation leader. This process involves employees from Dow Chemical, BPSC and the logistic service providers. The following figure 7 illustrates this principle.

![Figure 7;OTS failure collection key contacts.](image_url)

The overall OTS performance of the Telone supply chain together with the causes of the failure are then organized into a formal OTS performance format (see appendix A3) every month.

Before, the Telone OTS performance was reviewed at different levels of the S&OP monthly cycle (see appendix A2 for an extensive overview S&OP meetings). The input data for reviewing the OTS performance is the OTS performance measure format. Within the S&OP meetings there are different meetings with different participants. During each meeting the OTS performance of all the DAS business are reviewed and actions are taken where needed to improve the OTS performance. Currently, the OTS performances of the Telone Supply chain are not evaluated within the S&OP cycle. Therefore, also no actions are taken to revolve the OTS failures. The main reason for this is the influence of the low Telone OTS performance on the overall OTS performance of
DAS business. Next to this, interventions for OTS performance improvements were ineffective, no improvements were observed.

In order to understand the S&OP (meetings) that concerns the OTS review process better a description of the S&OP cycle is provided. Unfortunately, we cannot provide a detailed description regarding to the OTS performance meetings, this because there are currently no S&OP meetings that discuss the Telone OTS performance. Analysing the different S&OP meeting structure and the involved participants provided insights into the malfunctioning OTS review sessions.

**S&OP meetings**

Within The S&OP cycle OTS performances are discussed a couple of times at different S&OP meetings. The OTS performance measure is discussed at different levels of the S&OP cycle, where the first time is at the Supply review meeting. At this stage the OTS performance format is evaluated at this meeting and the OTS failures are needed to be addressed. At this stage the OTS performance is evaluated at a customer level or product level (GMIDS = product type). Then the OTS performance is again discussed at the RCU (-Pre) S&OP meetings, unresolved issues from the previous meetings are reviewed and addressed. At the GBU level, the OTS performance is discussed on a molecule level. A molecule level contains multiple product types which all have the same active ingredient (1.3 dichloropropene). Unresolved issues related to the OTS failures are first addressed at the Active ingredient meeting. Then the remaining unresolved issues are addressed at the GBL (Pre-) S&OP meetings. However, issues regarding shortage of resources are addressed at the GBU level as these decisions are needed to be taken at the tactical/ strategy level. Whereas, the RCU only addresses issues that involve operational activities and low investment decisions. Again, currently the OTS performance of the Telone supply chain is not discussed at the S&OP cycle because of the effect it had on the overall DAS OTS performance. It is therefore also not possible to point out who is responsible for a particular activity regarding decisions and responsibilities due to OTS performance.

**On time shipment performance**

The OTS performance in 2010 was on average 62%. From table 2, it is clear that on average there are 209 orders that go either to the customers directly or to the local warehouses are late or too early. The failures in the OTS performance are distributed as follows; 37 (18%) orders are delivered too early and 172 (83%) orders are delivered too late.

<table>
<thead>
<tr>
<th>Customer orders</th>
<th>Total (2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late/ early</td>
<td>209</td>
</tr>
<tr>
<td>Total</td>
<td>551</td>
</tr>
<tr>
<td>%</td>
<td>38%</td>
</tr>
</tbody>
</table>

Table 2; Lateness/ earliness (2010)

Appendix A5 includes the trend of the OTS performances (failure) of the Telone supply chain. We also have included the trends of each individual measurement point. From this trend analysis we see that the failures are higher in the high season periods.
Reported causes

For each delay a description for the cause of the lateness or earliness needs to be included. Causes for the OTS miss in 2010 are separated into five categories; logistic service providers, communication and information flow, respecting work procedures, capacity issues and unknown reasons. Moreover, about 60% of all lateness or earliness of orders do not contain a description of the possible causes for the misses (see table 3 for an overview for these causes). The main reason for this is that the implementation leader was not able to get a cause of the failure from one of the key contacts depicted in figure 8. The reason for this is that the persons that were responsible were not able to provide a clear reason for the failure. From interviews, it became clear that the involved key contacts were not aware of the OTS performance measure existence or that they did not see the importance of having an OTS performance.

<table>
<thead>
<tr>
<th>Reported causes for misses (2010)</th>
<th>Logistical service providers</th>
<th>Communication/information flow</th>
<th>Respecting work procedures</th>
<th>Internal capacity</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer orders</td>
<td>42</td>
<td>3</td>
<td>2</td>
<td>38</td>
<td>124</td>
</tr>
<tr>
<td></td>
<td>≈ 20%</td>
<td>1.4%</td>
<td>1%</td>
<td>18.2%</td>
<td>59.4%</td>
</tr>
</tbody>
</table>

Table 3; Reported causes for OTS failures 2010.

Logistic service providers.

In order to transport Telone material to customers, Dow AgroSciences cooperates with two different logistical service providers. These logistic service providers transport the Telone material from the Stade plant to warehouses or to customers directly. For the drumming customer orders Dow AgroSciences is cooperating with the logistic service provider “Geodis”. Next, for the Bulk customer orders “Bertschi” is used as the logistic service provider. The main reasons provided in the comment section is that trucks arrived too late, truck availability and that the trucks were not properly equipped.

Trucks that arrived too late at the Pape warehouse for drumming orders are mainly caused by the logistic service providers according to the OTS performance format. The logistic service providers were not able to arrange and send a truck on time. Because of this, it was not possible to ship the Telone orders on time from the Pape warehouse. Next to this, the Trans and Cis products are shipped in ISO containers which either are placed on trucks or on railcars. There are some issues regarding to the ISO containers, some ISO containers were not properly equipped because material was leaking out of the container. Because of hazard of the material this is considered as extremely dangerous and the Trans and the CIS materials were not loaded into the lacking ISO containers.

Another issue with the logistic service provider Geodis was that they also sometimes take orders earlier than the planned shipment date. This because they had an empty truck around the Pape warehouse and savings could be made by optimizing the truck shipment. However, at the end this has caused that 37 shipments were shipped too early than planned. It is clear that no good appointments have been made between DAS and the logistic service providers regarding earliness failures.

Communication and Information flow failure.

Some of the reported causes are linked to the communication and information failure category. A couple of causes which were documented are related to update failures of shipment dates. From interviews conducted
with the logistic service provider “Geodis” we also became aware that the shipment date of orders were rescheduled without informing the logistical service provider. A truck was then delivered on time whereas no products were available for shipment. Because of no communication between the drumming line and the logistic service provider, delays at the drumming stations are never communicated to Geodis. Because of this extra costs were made by the service providers which at the end were charged to DAS.

Respecting work procedures
This category of causes relates to the work procedures that are determined beforehand. Orders that are leaving from the drumming line are shipped to the Pape warehouse which is located nearby the Stade plant (2 km). At this moment the scheduler of the drumming line needs to enter the shipment date into SAP. It is also possible to perform this activity after the shipment date by backdating the shipment. From interviews we became aware that the responsible employees were not all aware of the backdating procedure. Because of this, orders were shipped on time physically but according to SAP these are delays.

Capacity issues.
Internal capacity is the second largest reported category for failure in the OTS performance, the main reasons for internal capacity issues are; manpower issues, and production delays.

The site logistic at Stade has issues with man-power capacity; this problem applies to the Telone loading stations for truck and railcar bulk. The shortage of man-power (operators of the loading stations) is causing that orders are loaded too late and OTS failures. The Telone drumming line also is facing capacity issues because of man-power shortage and therefore production delays are caused. The drumming line also faces problems with the delivery of empty drums (packaging material) and labels. Labels and drums are ordered just-in-time and therefore a delivery delay might cause a delay in the shipment date. The lead time of drumming orders is for some sizes 5 weeks, while the planning period is 4 weeks. Because of this the scheduler which obtains the drum plan from the planner cannot create a feasible scheduling plan. Because of space shortage at the logistic site of Stade it is not possible to stock empty drums. Also, for the labels it is not possible to keep stock as the artwork is changing a lot. Because of this it might be the case that labels are not usable.

OTS performance per packaging type
In order to see how the OTS performance is distributed we have separated the OTS performance per packaging type. In total we could distinguish 3 types of packaging processes (drums, truck bulk, truck railcar) over which the OTS is measured. First of all, from table 4 it is clear that we have far more drum orders than bulk for truck and railcars. We can conclude that the drum orders are shipped more on time than the truck bulk and the railcar bulk orders.

<table>
<thead>
<tr>
<th>Packaging Type</th>
<th>Drums</th>
<th>Truck bulk</th>
<th>Railcar bulk</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late / early</td>
<td>106</td>
<td>75</td>
<td>28</td>
<td>209</td>
</tr>
<tr>
<td>Total</td>
<td>316</td>
<td>163</td>
<td>47</td>
<td>526</td>
</tr>
<tr>
<td>%</td>
<td>66%</td>
<td>54%</td>
<td>40%</td>
<td>60%</td>
</tr>
</tbody>
</table>

Table 4; delays for Drums, truck Bulk and Railcar bulk (2010).

Interviews with the scheduler and logistic service coordinators.
From the interviews conducted with the scheduler and the logistic service coordinators we have found that there is a robustness issue with the available OTS data of 2010; this concerning the reported OTS failures. We also have found out that the interviewees were not aware of the OTS performances and that they were questioning the causes reported to the OTS failures.
4.4) Summary
To conclude, from this detailed analysis a good insight have been obtained regarding the OTS performance. Instead of improving the OTS performance by revolting issues reported in the OTS format, it is wiser to evaluate the OTS performance measurement process. From the collected data and the interviews it has been found that the OTS performance and the causes for delay are not robust. No proper actions could be taken based on the available OTS data. This might also explain why the S&OP OTS review session were ineffective in addressing the OTS failure issues. Therefore there is an urgent need to evaluate the current OTS performance measurement process and aspects surrounding the measurement process cycle such that useful data from which proper corrective actions can be taken on is established.
5) Evaluation OTS performance measurement process

In this chapter the OTS performance measure of the Telone supply chain will be evaluated according 9 criteria found in literature. These criteria are needed to assess whether the current OTS performance measurement process is appropriate. Based on this evaluation we would like to bring forward recommendations which indicate how to redesign the current OTS performance measure such that a (good) performance measure is obtained.

5.1) Performance measure evaluation

A couple of main themes raised up in literature concerning appropriateness of performance measures are selected. The article of A. Neely et al (1997) summaries main findings from literature concerning what a good performance measure needs to look like. This article proposes in total 22 recommendations that indicate what a good performance measure needs to have. The paper of C. Caplice and Y. Sheffi (1994) also proposes 8 criteria by which one can assess logistical performance measures like OTS. From these two articles, we have selected 9 relevant criteria which we will use to assess the OTS of the Telone supply chain (see appendix A6 for the complete set of recommendations). The remaining criteria which were not selected are addressing topics which fall outside the scope of this research project. A couple of criteria mentioned by both papers are addressing costs related to performance measure, here the consideration of introducing a performance measure or not is discussed. Next to this, another topic left outside this study is the alignment of performance measures with IT systems.

The following criteria are included within this study; Importance, Target, Frequency, Robustness, Usefulness, and Control. After explaining each criterion an assessment of the criterion regarding the Telone OTS performance measure will be provided.

Importance

According to C. Caplice and Y. Sheffi (1994) a performance measure should relate or be derived from strategy, and they argue that if a metric is not related to any business objectives then one can question whether the measure should be introduced. Hence one needs to identify the business objective from which the performance measure is related to.

*DAS aims to achieve and maintain a “class A” MRP performance. Class A performance is the highest rating level concerning the execution of supply chain operations. The main focus is to have the best customer service with lowest costs. In order to achieve A class performance companies need to perform acceptable against objective standards. One of the standards is the OTS performance measure which needs to be at least 95%.*

However, DAS is not owning all resources used at the Telone supply chain. DAS has outsources the production, packaging and the operational supply chain activities to other businesses within Dow. DAS is the owner of the metric while most of the resources that influence the OTS metric are owned by other businesses. During our interview sessions we became aware that employees that are performing activities which determine the OTS performance were totally not aware of the existence of any OTS performance metric. It is because of this also logical that they did not feel responsible to improve or even pay attention to the OTS performance. So, the OTS metric has a strong link to the strategy of the DAS business. However, from the interviews we became aware that the other business did not share the same view concerning the importance of the OTS importance. This is mainly because of having an OTS performance level of at least 95% is not part of their goals. Moreover, responsible employees are not reviewed by the upper management on the Telone OTS performance of their processes.

Targets

The objective of a business is related to the requirements of its owners and customers. The level of performances that are needed to satisfy these requirements depends on how good the competitors are and the
associated costs. The level of a performance measure needs to be such that the users of the metric are able to improve the metric in order to achieve the predetermined target. Therefore targets needs to be reasonable such that it motivates the users to put effort and time in improving the performance. Enabling users to improve performances also involves making resources available.

In order to achieve an “A class” performance, it is necessary that the On-Time Shipment performance needs to be at least 95%. Therefore, the target for On-Time Shipments is directly established on a strategic level. Next to this, a 95% On-Time shipment performance incorporates different orders (MTO/MTS) and packaging types (Bulk, Truck, Train). No distinction has been made between MTO and MTS orders. One can question whether these two orders are needed to be treated similarly regarding On Time shipment. Next to this, from interviews with the LSC of the Bulk railcar loading station we know that the loading stations for railcar is facing a resource shortage problem. Because of this, the OTS for railcar is performing below the service standard. The main conclusion that could be drawn from this is that the target is clear and simple but one can question whether it is realistic to treat all orders similar and whether the target for the loading station for railcars is appropriate. Moreover, regarding the case of resource shortage it is also important to mention that this problem could not be addressed when there are no review sessions regarding OTS performance. Because of this OTS failures cannot be addressed and the OTS failures will not be solved. The decision about treating MTS and MTO orders equally from the OTS performance standard is something which needs to be addressed at the strategic level.

Frequency

The frequency with which performance should be recorded and reported is a function of the importance of the measure and the volume of data that is available.

Every week there is a data collection process for measuring the OTS performance during the past seven days. This process is currently executed by the implementation leader. From the planned shipment date and the actual shipment date OTS performance of the last seven days is calculated. Next to this, each failure in OTS performance needs to be explained and therefore a comment for defect needs to be added to a failure. In order to add a comment to the OTS failures, the improvement leader needs to communicate with the employees of Dow Chemical, BPSC and the Logistic service providers. Earlier in the importance criterion we have mentioned that the involved parties within the Telone supply chain do not share the same importance level towards the OTS performance. Therefore, it is extremely difficult for the improvement leader to collect useful information from which corrective action can be taken if needed. With useful information it is meant that the responsible key contacts do not take the effort to provide a cause for failures or that they do not remember anymore why a particular order was late for example. This is also the reason why about 60% of the failures do not have a clear comment for the failures.

Measuring the OTS performance on a weekly basis is appropriate because of the data collection timing of the causes of the failures. If a longer period is chosen for the data collection process it might be the case that the responsible employees do not remember the causes for particular failures. Documenting these failures at the end of the day will take away the problem of not remembering the causes for failures.

Robustness

A metric is robust if it is widely accepted, interpreted similarly by different users and can be used for comparisons across time, locations, organizations and is repeatable. A metric need to be widely accepted by all parties involved in the process over which the metric is measuring the performance. Next to this, the metric itself needs to be simple and easy to understand. Most of the time metrics are simple ratios that capture performance in one number. The way how the performance level is reported needs to be such that it is easily to compare past performance and performance of other departments/organization easily.
The metric itself is very simple and easy to understand, this because of the easiness of the calculation and the way how it is reported. A single number (ratio) is used to represent OTS performance, which could easily be used to compare over time and a cross different locations and organizations. However the current OTS performance data (failures and the score) are not repeatable in the sense that the different employees from the OTS measurement points could not agree with the reported OTS data.

**Usefulness**

The usefulness of the performance measure relates to the readiness of the users to understand the metric and to provide a guide of action to be taken.

The current OTS performance measure does not score high on the usefulness criteria, this partly because of the abstract level at which the performance is evaluated. For example, the loading station for bulk trucks does not easily see what its share is to the overall OTS performance measure. Aggregating the OTS performance over the different loading stations or processes too early makes it difficult to understand what contribution is of each process over which OTS is measured to the overall OTS performance (See appendix A4 for the OTS performance format).

**Control**

Once the OTS Monthly performance is determined and organized into the OTS performance format (see appendix A4), it is important that there is a control process which needs to act on the OTS failures. The question “What do they do with the information that is collected is probability one of the most important questions, this because unless the management loop is closed, there is no point in having an OTS metric (A. Neely et al (1997)).

Once the OTS performance is measured on a weekly basis and is aggregated into the monthly format no actions are taken to improve the OTS performance. This because the Telone OTS performance review process is removed from of the S&OP cycles.

Normally, within the S&OP cycle the OTS performance is discussed a couple of times during different meetings with different participants. In short we could say that the S&OP meeting is designed that it also addresses issues with the OTS performance measure. Before, the following participants where of the S&OP meetings where involved at the Regional Commercial Units; Supply chain planning specialist, the distribution resource planner, logistical specialist and the detailed production specialist. At the Global Business unit S&OP meetings the following members are included; Molecule supply chain manager, production coordinator, site supply chain specialist, site production leader, and site quality leader.

However when taking a closer look at the S&OP meetings it becomes clear that no participants from Dow Chemical, BPSC were joining in the S&OP meetings. Having this said, we also know that all the resources and assets used for the Telone production are almost all owned by Dow Chemical. This might be the reason why no action could be taken to resolve OTS failure issues as the resources were not owned by participants included in the S&OP meetings. Moreover, as the S&OP meetings precede throughout the month the more abstracter the OTS performance is reviewed. At the RCU level the OTS performance can be evaluated only at the product level, whereas at the GBU the OTS performance is reviewed at a molecule level which involves multiple product types.

**Conclusion**

To conclude, from this evaluation we have found that not all parties that are involved at the Telone OTS activities are sharing equal importance level regarding the OTS performance. Next to this, targets defined for the OTS performance are clear and easy to understand. However no differentiation is made between MTO and MTS orders. We also have found that during the measurement process the representatives of the different measurement points do not document OTS failures. Moreover, the current OTS measurement data are not repeatable which puts questions towards the robustness of the data. However the OTS performance is easy to

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be compared to other Dow businesses. The usefulness of the OTS performance regarding the different measurement points within the Telone supply chain is not appropriate. Each measurement point does not know what their share is to the overall OTS performance. At the end we also have found that currently there is no review process which evaluates and reviews the OTS failures.

5.2) Recommendations

From the OTS performance measurement process a couple of findings are brought forward which indicate the shortcomings of the OTS performance measurement process. In this part we would like to bring a couple of recommendations forward that needs to address the shortcomings of the OTS performance measurement process.

Importance

OTS improvements are only possible when all parties that are involved in the OTS processes sharing the same view towards the importance of the Telone OTS performance measure. Moreover, next to the OTS improvements it is also difficult to collect repeatable data regarding OTS performance failures.

The essential missing part within the cooperation of Dow Chemical, BPSC and Dow AgroSciences is the existence of service level agreements. When outsourcing activities to another business it is important to state or agree at which level these services needs to be executed. Barratt and Oliveira (2001) found that a major barrier to the development of collaboration was the lack of front end agreements as to specifically what organizations were going to collaborate over. Because of this, **DAS needs to establish service level agreements with the involved parties Dow Chemical and BPSC.**

Targets

Targets used for the OTS performance measures are set equally over all order types and packaging types. In essence the targets are very simple and easy to understand, but no distinction has been made between MTS and MTO orders. These two orders are treated similarly and both orders need to have an OTS performance level of at least 95%. One can question whether it is beneficial to include MTS orders in the OTS performance as these orders do not directly influence customers. Moreover, because these orders are treated similarly it might also be the case that no priority is given to MTO orders. Because of this, we recommend to evaluate the importance of MTS orders which is not influencing the customer when it comes to OTS performance failures. More attention than can be devoted to the MTO orders for which there is a specific customer order.

Frequency

For the frequency criteria it was mentioned that every week there is an OTS performance collection moment regarding the OTS failures. However, often responsible employees could not remember what the specific cause was for a particular failure. Therefore we would like to recommend that each failure in OTS performance needs to be documented at the end of a working day. This data needs to be sent at the end of the week to the implementation leader.

Robustness

The repeatability of the data is one measure issue when it comes to the OTS performance measure; this is mainly because no attempt is made by DAS to point out at which level the OTS performance needs to be executed. Therefore this point relates to the importance level of the OTS performance. Having a clear performance target which is part of the employees goals needs to put pressure on the employees to address OTS failures.
**Usefulness**
Currently the level of usefulness is not appropriate because it is not possible to point out what the contribution is of each process or department to the overall OTS performance. Therefore we suggest that at the weekly collection points the OTS performance needs to be separated into the different transportation modes. Thus, *for each process over which the OTS metric is measured a separate score is kept*. At the end of each week there needs to be three different OTS scores for each transportation mode. Because of this, the format that is used needs also to be changed such that there is space to distinguish the different transportation modes and order types.

**Control (Closed Loop)**
The article of A. Neely et al (1997) argues that in order to perform actions on acceptable or unacceptable performance a continuous improvement group is needed that identify reasons for poor performance and to make recommendations regarding how performance can be improved. This continuous improvement group needs to be such that the right people are included.

In order to review the OTS performance within the S&OP meetings the right participants needs to be included into these meetings. Before, participants from the Dow Chemical and BPSC have been included into the Telone OTS review meetings. Therefore it was not possible to address OTS performance failures at the S&OP meetings as the resources over which the OTS performance was measured are not owned by DAS.

In order to illustrate the different businesses involved and which participants are to included from each hierarchical level figure 8 is included.

![Figure 8; S&OP cycle meetings.](image_url)

The first OTS review sessions needs to take place at the Supply meetings of the S&OP cycle. We have mentioned earlier that the level of detail needs to be such that at the end of each week we have collected and presented OTS performance separately for each process (drumming /Bulk truck/ Bulk railcar). Because at the Supply meeting the OTS performance is discussed at a product level there is room to deal with separate performances of the different OTS measurement points. At this stage, we also want to add the following representatives to the Supply meetings; Scheduler drumming line, logistic service coordinator Bulk truck and the logistic service
coordinator Bulk railcar. At this point the OTS performance is discussed at a monthly meeting and issues regarding OTS failures are addressed. Then, unresolved issues that systematically come back and for which decisions are needed from a higher hierarchical level needs to be fed into the GBU S&OP meetings. The OTS performance concerns mainly resources from the site logistic department at Stade owned by Dow Chemical and therefore at the GBU level the site logistic specialist or leader needs to be included into the A.I meetings. At his points the site logistic specialist or leader needs to review the OTS performance and failures. Moreover, at this point OTS issues that involve tactical or strategic decisions needs to be addressed. One example for this is the manpower issue of the drumming line.

At each monthly A.I meeting the site logistic specialist or leader should know what the performance is of the different processes executed at the site logistic department. Based on this review, the site logistic will have an overview of the share of each process towards the OTS performance. Therefore, more specific actions can be taken to address OTS failure of each process.

Together with the service agreements and the active participations in the S&OP meetings of Dow Chemical and BPSC representatives, needs to create a close loop regarding the OTS performance measurement. The thick black lines within figure 9 represent the information flow of the OTS, whereas the red line represents the members that are involved form Dow Chemical. The main idea of this figure is to depict that people from the site logistics and from BPSC are needed to be incorporated to the Supply S&OP meeting (red line) and that a close loop is designed which enables continuously improvements regarding OTS (black line).
5.3) Implementation process
At this point we would like to point out how the different steps regarding OTS measurement process improvement needs to be implemented.

1) First of all service level agreements needs to be established with Dow chemical and BPSC, this agreement level needs to indicate at what level the outsourced tasks needs to be executed. Next to this, we also need to indicate which employees need to be included in which OTS review process.

2) The next step is to establish the OTS improvement team within the S&OP meetings, for this we would like to point out that the Implementation leader needs to be the leader of this team. The following participants of the other businesses are needed to be included;
   a. RCU level; Drumming line Scheduler, logistic service coordinators from the loading stations (Telone bulk truck and bulk railcars) and the LSP’s.
   b. At the GBU level; Implementation leader, site logistic leader of the Stade plant, logistical specialist and the operations manager supply chain planning of the BPSC.

3) At the weekly measurement point’s failures and OTS performance needs to be separated according to the three measurement points (Bulk truck, Bulk railcar and drumming line). Next to this, at each measurement points the OTS failures needs to be documented at the end of each day. These document need to be send to the Implementation leader which then organize the results into the monthly format.

4) Redesign the OTS Monthly format such that for each measurement point there is an OTS monthly performance and causes for the failures.

5.4) Concluding remarks
A couple of interventions have already been made during this project regarding the OTS performance. First of all, because of the empty drums order lead-time the planning horizon of the drumming orders has been extended to a feasible scheduling plan that can be made. Next to this, trainings regarding backdating procedure for the drum scheduler has been given by the implementation leader.

During the observation phase it became clear that no formal inventory policies existed for the intermediate storage tanks. Moreover, according to the production engineer of the Telone supply chain high numbers of overflows have been found within one of the intermediate storage tanks (AV-1006). From interviews we have concluded that overflow instances are caused by a lot of bad ad hoc decisions which have been made and which eventually have caused misses with the OTS performance. Unfortunately, it is not possible to support this with the available data because of the robustness of the reported OTS misses.

Next to the OTS measurement process improvement project we also have addressed the lack of inventory management policy at the AV-1006 storage tank. This research project will be handled in chapter 6.
6) Inventory management AV-1006 storage tank
In the previous chapter, we have mentioned in the Concluding Remarks subsection of the previous chapter that there is currently no inventory management policy for the intermediate storage tanks in the Telone supply chain. Therefore, this part of the report will deal with the lack of inventory management at the intermediate storage tank.

First there will be a description of the problem definition at hand regarding the inventory management of the AV-1006 storage tank. After this the mathematical model linked to this project is introduced. Chapter 8 involves the verification and validation steps of this project. Chapter 9 concerns the scenario analysis of the developed mathematical model. Chapter 10 discusses the implementation of the model.

6.1) Problem definition and research assignment
In this subsection the problem definition of the inventory management project will be explained. Next to this, a literature summary provided regarding this project will be provided. Then the research assignment of this project will be formulated. At the end the research approach and the scope of this project will be handled.

6.1) Problem definition
During our orientation phase we became to the conclusion that no formal inventory policies exist for the intermediate storage tanks. More specifically, according to the production engineer of the Telone supply chain high numbers of overflows have been found within one of the intermediate storage tanks (AV-1006). Because of the continuous production, autonomous supply and demand decrease (legislation EU) more pressure is put on the intermediate storage tank (AV-1006).

Currently the following actions are used to reduce the overflows at the AV-1006 storage tank; throughput reduction and shipping Telone material to the Botlek tank. The result of the interviews stated that the current overflow interventions are made ad hoc and eventually these decisions also might affect the OTS performance of the Telone supply chain. Unfortunately, it is not possible to support this with the available data because of the robustness of the reported OTS failures. In order to explain the relationship between the overflows at the AV-1006 storage tank and the OTS performance we have included figure 10. Business activities are often seen as processes which convert inputs into outputs through some applied work. The On-time shipment performance measure can be seen as a measure of the quality of the process in terms of completion time. Next to this the OTS performance measure might also influenced by the availability of the input material which is processed.

Overflows and stock-outs
The inputs of all the processes included in figure 5 are storage points where intermediate or finished materials are stored before getting packed or loaded at the loading station. Having no materials available in these storage tanks might have a direct effect on the OTS performance (lateness failure). On the other hand having high levels
of stock at the intermediate storage points might mean that orders are needed to be brought forward (earliness failure). Next to the effect on the OTS performance, overflows at the AV-1006 limited capacitated storage tank has also caused that the preceding Telone process unit needed to lower its throughput. The Telone supply chain of Dow AgroSciences considers this as a production loss. The main reason why they have defined this as a production loss is because there is more demand than supply for the Telone products on a global level. However, reducing the throughput of the Telone supply chain is limited as the preceding storage tank AV-1008 has also a limited capacity to store raw material. Burning the Telone material is the only option to consider in this case, as we deal with an autonomous supply of raw materials.

**Overflow at the intermediate Storage tanks**

According to the production engineer of the Telone process unit no formal inventory policies are in use to manage the storage tanks and because of this unnecessary production losses are introduced. The table 5 below shows the blocking effects caused by full buffers on the Telone production unit.

<table>
<thead>
<tr>
<th>Year</th>
<th>Product type</th>
<th>Production losses in MT</th>
<th>Reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Telone</td>
<td>401,5</td>
<td>Full Tank (AV-1006)</td>
</tr>
<tr>
<td></td>
<td>Full Tank (AV-1006)</td>
<td>241,3</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: production losses

Table 5 above indicates the total amount of production losses that are caused by a full AV-1006 storage tank. In 2010 there was a total production loss of 401.5 MT. At the beginning of 2011 more than 240 MT of finished Telone is lost because of a full tank.

**Production losses**

A production loss is determined at the end of each day, and can be caused by a full Tank (AV-1006) and by the availability of raw material. The difference between the maximum available production capacity and the actual production capacity is what is called a production loss (throughput reductions).

However it is also possible to have throughput reductions while the storage tank AV-1006 is not full. Thus, there is space left to store more Telone in the AV-1006 storage tank but no direct demand is available. This might seem to be strange as we have mentioned before that within the overseas market there is always demand for the Telone products. However because of limited flexibility in which the overseas markets are served it is not always possible to serve Telone to the overseas markets. Therefore it might be more beneficial to lower the throughput and to increase it when the right flexibility is at place. For example, if there is a shortage of railcars to send Telone products or there is not enough volume to arrange an overseas shipment might be the reasons to reduce the throughput and to spare on the inventory holding costs until the right moment is reached where the right resources and volumes are reached. On the other hand it is also possible to have a throughput reduction because there were no raw materials available.

**Production loss trend**

In figure 11 The overflow trend of 2010 and the start of 2011 are depicted. From this figure we can see that the overflow issue is mainly observed in the start and at the end of 2010. This is because we deal with seasonal products and outside the high seasons fewer products are sold therefore the AV-1006 storage tank level increases.
6.2) Inventory management Literature review summary

From our literature review a couple articles have been found that are addressing buffer management in a flow lines. Exact solutions or models are provided in literature only for very small production lines which contain only two stations in tandem with a buffer ahead each station. These exact solutions are mainly closed form models or state-space models. Next to exact solutions, there are also approximate models provided in literature. The most common approximation method is the decomposition, which means that large systems are decomposed into smaller subsystems for analysis. Models that approximate these production lines are included in the following papers. The article of Gershwin (1986) proposes a decomposition method which is used to evaluate performance measures for a class of tandem queuing systems with finite buffers in which blocking and starvation are considered. However, analysing the steady state behaviour of a system would only be relevant if one is interested in the long term behaviour of the system. Next to this, a characteristic of analysing a system in the long term behaviour is that it is independent of the initial inventory level. This might be inappropriate when analysing buffers on a short term horizon. Our interest in this project is to analyse the behaviour on a short time period. However in literature some authors have considered queuing models that are based on the transient analysis of the production system. Up to now however there are no articles known in literature that address general arrivals and departures times in the transient states.

Within the process industry literature a lot of attention has been given to address problems from the batch industry. This project concerns a continuous process flow instead of a batch process flow. Within the Batch industry literature mixed integer linear programming (MILP) optimization models are widely used to solve supply chain problems within process industries. J. Kallrath (2005) provides an overview of the state of the art and the recent advances in MILP models used to solve planning and design problems in the process industries. Again, from this overview one can see that most of the solutions are designed to address batch systems within the process industry. Nevertheless, the studies of Kallrath (2005) are providing valuable insights on the points to consider in the modeling stage of using MILP models. This especially for the planning models in the process industries. Valuable insights have been obtained from these studies in terms of general characteristics and aspects to be included in the modeling stage.

According the article of K. Bakhrankova (2008), continuous flow production systems are less researched with respect to specific theoretical and optimization issues. This has to do with the lack of consideration of variety in process industries. Moreover, due to the process complexity observed within this production environment, the
focus has been on process control and automation. Therefore less emphasis has been made on production planning in the continuous flow industries from an operational research point of view. Same conclusion has been drawn by A. Shaik, C.A Flauas, J. Kallrath and H. Pitz, (2009). They have mentioned that the short term and medium-term scheduling problem of continuous plants has drawn less attention in the literature compared to that of batch plants, although the continuous units are common in the chemical process industries.

K. Bakhrankova (2008) is one of the few papers that address continuous production of a chemical plant with a completely continuous multi-stage process. The goal of the (DSS) is to better utilize the production capacity by providing integrated cross-functional planning solutions, where the decision rules are defined by MILP models that synchronize production and distribution. This paper develops a single site custom designed planning application for a completely continuous production system, with no setup times/ costs or stoppages are necessary to switch over between products. The system considered has a divergent material flow, where each product has a dedicated routing through machinery and intermediate storage tanks. Using a set of specialized materials, this facility manufactures a range of non-discrete commodity products. Moreover none of the produces are wasted as they can be reprocessed or mixed to meet the final product specifications. The production has also a capacitated inflow. The demands are deterministic within the short-term and up dated via rolling planning horizon. However there are two very important conditions of this model; the customer service level is 100 %, no backorder or stock-out situations allowed, and the inventory of finished product is used as buffer between continuous production and discrete shipments to guarantee the lowest freight rates.

One of the main characteristics of the Telone supply chain is the autonomous supply of raw materials form the suppliers. This means that it is not possible to refuse any supply from the suppliers, instead disposing (our case burning) options needs to be considered when the material cannot be stored (or is not needed). The paper of C. Erag et al (2007) addresses an inventory management problem where there is stochastic external demand and an autonomous supply (independent return flow). Next to this, there is an option to dispose stock at fixed costs and with a fixed lead-time. They consider a continuous review replenishment policy. There study extends classical inventory policies by including possibilities to allow for disposal of excess stock. However these authors consider a single storage point where material is disposed when not needed.

**Conclusion**

Next to the performance measure literature, we also have found that there is no appropriate queuing literature which addresses process flows. This mainly because of the long term behavior (steady state) focus of many papers within that use queuing theory. A couple of articles have addressed the transient behavior of process systems. However no attempts have been made to address production systems with general distributions. Moreover, within literature there is very little research done on continuous process industries, instead a lot of attention has been devoted to the batch industry. Nevertheless, within the batch industry a lot of articles address planning problems by using MILP models. These papers are addressing aspects from the Batch industry which are similar for the continuous process industry and therefore could be useful for this project. Next to this, there is also a clear lack of articles that have attempted to address autonomous supply within a process flow system where disposing options are available.
6.3) Inventory management Research assignment
Currently, production losses are mainly addressed by reducing the throughput of the Telone process unit. This again resulted in production losses as there is globally more demand than Telone supply. Because of this, we would like to benefit from the fact that overall there is less supply than demand by allocating some Telone products to overseas trade markets. Allocating Telone II material to the overseas markets needs to be done by minimizing stock-outs of the current internal markets.

Neumann et al (2002) distinguishes three planning levels, where strategic decisions are made at the long term planning level, the tactical decisions are taken at mid-term planning level and the detailed operational decisions are made at short term planning level. The long term planning is defined in years, whereas the mid-term is defined in months or number of weeks and the short term planning is defined in weeks or days.

In this case, overseas shipments decisions are needed to be executed on a mid-term planning level, this because this decision concerns multiple variables or constraints that influence or are influenced by the overseas shipment decisions. These variables mainly concern the following aspects of the Telone supply chain; autonomous supply of raw material, burning volumes, Telone process unit (throughput, capacity), capacity of drumming and loading stations, intermediate storage tanks (capacity), and railcars used for transportation. Next to this, overseas shipment needs to be decided by considering the stock-out instances of the current Telone trade markets. In order to pursue for a continuous OTS performance improvement we also would like to take into account the effect of shipping Telone material to the overseas markets on the OTS performance. This by restricting that at maximum 5% of the orders might be shipped to early or too late. Therefore the following research assignment has been formulated;

Design a mid-term planning tool which indicates how much and when to ship Telone material to overseas trade markets (spot markets), while taking into consideration the relevant variables of the Telone supply chain and the stock-out, overflow and OTS performance misses of the current trade markets.

6.4) Inventory management project Scope
In order to address the shortage and the overflow instances at the AV-1006 storage tank the scope has been set from the raw materials that are obtained from the suppliers up to the drumming and loading stations. The Trans and Sic products are left out of the scope this because of the very small influences on the decision that is taken to ship Telone II to the overseas markets. The total amount of Cis and Trans products that is sold is not more than 4% of the total Telone II sales volumes. Moreover the Cis-Trans separation process unit is only turned on (1/3) of its available capacity (hours) during the year. Next to this project also does not consider shipment vessel costs. This because of the time constraints of the project. Burning options of the Momentive suppliers is not taken into account within this project. This mainly because we currently have the T556 LBC storage tank in use which reduces the likelihood of reducing the probability of burning at the Momentive site.
6.5) Inventory management Research Approach

For this project first a thorough analysis of the supply chain analysis has been conducted, from this analysis a problem definition and the research assignment have been formulated. Then a detailed analysis regarding inventory management of the intermediate storage tank AV-1006 has been provided. Within the conceptualization phase a Mathematical model has been designed. Then a verification and validation is conducted regarding the designed model.

Figure 12; Scope inventory management project.
7) Mathematical model
In order to address the overflow instances at the intermediate storage tank (AV-1006), a mathematical model has been constructed. First of all we would like to explain what the model is expected to do and how it needs to be used. This section also provides the assumptions and the simplifications that have been made during the development of this model.

7.1) Objective of the Mathematical model
The designed mathematical model is build such that it needs to assist planners regarding overseas shipments. The model indicates timing and the volumes that needs to be shipped to the overseas trade markets; this to overcome overflows and stock-outs instances at the AV-1006 storage tank. The model also addresses the OTS performance standard by guaranteeing that at least 95% of the Telone material needed for drumming and the loading stations is available.

Overflows instances are up to know mainly solved by either shipping material to the Botlek tank or by reducing the throughput of the Telone process unit. However, there are more options available which can be used to address Telone tank overflows. In short, we will present the available options;

- Overseas shipments
- Bring drumming orders forward
- Bring Bulk orders forward
- Reduce throughput of the Telone process unit

Overseas shipments of Telone material is addressed directly by the mathematical model, and needs to help to overcome overflows at the Telone storage tank. Bringing bulk and drum orders forward is not included in the model and needs to be addressed outside the model. This because there is no storage point available for these orders and therefore the planner needs to contact the customers for this.

When the mathematical model decides to ship Telone material to the overseas trade market there might be a stock-out instance at the AV-1006 for the internal markets. Instances where there is low demand from the internal markets the model might prefer to allocate Telone material overseas as more revenue is generated. One could send less Telone material to the overseas markets when instances of stock-outs appear. However this option needs to be considered outside the model.

7.2) Application level of the Model
This mathematical model is designed to be used at a daily basis for a planning horizon of 3 months. The reason why it is chosen to make decisions at a daily basis is because of the variability in the production throughputs.

Figure 13 below illustrates difference between the actual production levels and the forecasts. As figure 13 depicts the actual production level fluctuates considerably at a daily than was forecasted. Therefore aggregating the decision moments into a weekly or monthly basis might not address overflow instances.
This model is not proposed to be used for daily operational scheduling of the Telone drumming and production. It can be used to perform scenarios regarding the number of railcars needed and to investigate the effects of different tank sizes. This model includes a rolling horizon, this to update demand, raw material forecast and the inventory levels of the intermediate storage tanks.

7.3) Model simplifications and assumptions
The model is based on the Telone supply chain of DAS in Stade. Assumptions have been used in cases where no information was available or in order to simplify the model. In this part we will discuss the main simplifications and assumptions which have been made during the modelling phase.

Simplifications
A couple of simplifications have been made regarding the logistical process of the Telone supply chain. First of all, we do not consider vessel shipment costs as this is depended on the type of contract. Next to this, we also have simplified the model such that there is always demand and storage space available overseas to unload Telone material. We also have aggregated over the secondary warehouse, therefore only the Pape (primary warehouse) is included in the model. AV410 and the AV412 are left out of the model as these are very small storage tanks which do not influence overseas decisions as the material level of these tanks is very stable.

The model does also not consider the scheduling of the burning, and loading stations, this mainly because of the involvement of products from other businesses. In order to indicate when there is available capacity to burn material or to load bulk trucks and bulk railcar orders we need to consider activities (operations) of other businesses within the Stade plant. However, because of time restriction and the complexity this adds to the model it has been chosen to leave this out.

Assumptions
The planning horizon that has been used for this is model is 3 months. An overseas shipment needs to be arranged one month before actual shipment date. Therefore, in the first month the overseas shipment decisions are taken and in the second month the overseas shipment are observed (executed). Because of the behaviour
(no stocks at the end of the horizon) of the model at the end of the finite horizon, an extra month has been included to overcome influences of the models behaviour at the second month.

The Raw material supplied by Momentive is restricted by the annually forecast supplied by Momentive. Therefore the supply of raw material needs to be equal or more than is indicated by the forecast of Momentive.

Production that is started at a particular day will become available at the end of that day. Next to this, we also do not consider planned maintenance operation of the production unit as these are executed once in five years.

For the packaging phase we only consider the packaging capacity of the drumming lines and assume that there is enough manpower and packaging material available. It is not possible to incorporate these factors without considering drumming lines of other businesses. For example manpower is not only determined by the Telone drumming line but also by other drumming lines from other businesses.

- The packaging department operates 5 days a week, each day has 10 drumming hours. No overtime hours are available.
- Setup times needed for changing from drumming sizes are short and therefore neglected.
- We only consider variable burning, inventory holding, conversion, production loss and railcar costs. Fixed costs are not incorporated within this model because they do not influence the outcomes of the model.
- Conversion costs are approximated by a linear function.

7.4) Type of mathematical model

In order to address the overflow instances at the intermediate storage tank (AV-100G) a mixed integer linear program has been constructed. The reason why we have chosen to use an analytical model instead of a simulation study is because it is known that a simulation study or the results can be difficult to interpret. This because a simulation is based on random variables, it can be hard to distinguish whether an output is the result of the systems interrelationship or because of the randomness. Moreover, simulation studies produce only estimates of the model output variables for a particular set of input parameters. Whereas, an analytical model like MILP produces the exact true characteristics of the output variables. However, complex systems with stochastic elements are too complex for analytic analysis. For these systems a simulation is then the only possible option.

Before explaining the model, a picture (figure 14) is included in the next page which depicts the Telone supply chain and the decision variables that the model will solve. Next to this, the formal representation of the objective function, decision variables and constraints are given together with the parameters in the next pages.
7.5) Telone process flow

Figure 14; Telone Supply chain with decision variables.
Sets

\( I \) = Type of drumming order, \( i = \{1, 2, 3, \ldots, 17\} \)

\( H \) = railcar locations to ship crude of finished Telone

\( J \) = intermediate storage location, \( j = \{1, 2, 3, 4\} \)

\( S \) = time period( days ), \( s = \{AV - 1006, AV - 1008, Botlek, Papel, TSS56\} \)

\( T \) = time period( days ), \( t = \{1, 2, 3, \ldots, 90\} \)

\( Z \) = burning flows

Parameter declaration

\( A_{\text{all}} \) = Allocated Telone II material for Drumming orders during period \( t \).

\( B_{\text{costs}} \) = Burning costs (€/MT/day).

\( C_{\text{con}} \) = intercept of the conversion costs function.

\( c \) = slope of the conversion cost function.

\( C_{\text{railcar}} \) = Variable operational railcar costs per railcar shipment (return) in (€).

\( C_{1} \) = Factor used for material loss (Crude Momentive) during Telone production.

\( C_{2} \) = Factor used for material loss (Crude Allyl) during Telone production.

\( D_{\text{i,t}} \) = Demand forecast customer drumming orders during period \( t \).

\( D_{\text{bulk,EU,t}} \) = Demand forecast Bulk orders within EU during period \( t \).

\( d_{h} \) = Volume (MT) of Telone shipped to Botlek storage tank for overseas shipments during period \( t \).

\( e_{h} \) = Volume (MT) of Telone shipped to Momentive to TSS56 storage tank during period \( t \).

\( f_{h} \) = Volume (MT) of Telone shipped from TSS56 storage tank to AV - 1008 during period \( t \).

\( G_{s} \) = Shortage quantity of Telone material for Truck loading station during period \( t \).

\( INV_{\text{end}} \) = The inventory level of location \( h \) at the end of the period \( t \).

\( K_{s} \) = Shortage quantity of Telone drumming orders at the Pape warehouse during period \( t \).

\( l_{s} \) = Volume (MT) of Telone shipped from Momentive to AV - 1008 during period \( t \).

\( m_{\text{railcar,s}} \) = load time railcar shipment.

\( m_{\text{vessel,s}} \) = load time vessel shipment.

\( M_{1} \) = Big M used for overseas shipments.

\( M_{2} \) = Big M used for Allyl supply to either the Telone process unit or to the AV - 1008 storage tank.

\( M_{3} \) = Big M used for the restriction of at least OTS performance of 0.95%

Max \( c_{s} \) = Maximum storage capacity for "s" in (MT).

\( M_{\text{shipment,s}} \) = Minimal shipment overseas shipment level.

\( OTS_{0} \) = On - Time shipment performance standard Pape warehouse (drumming orders).

\( OTS_{s} \) = On - Time shipment performance standard loading station (Trucks).

\( P_{\text{inflow}} \) = Minimum inflow capacity in (MT) to the Telone production unit during period \( t \).

\( P_{\text{sales}} \) = Sales price of "i" orders during period \( t \).

\( P_{\text{bulk,EU}} \) = Sales price of bulk EU during period \( t \).

\( P_{\text{overmax}} \) = Sales price of bulk overseas during period \( t \).

\( P_{\text{max}} \) = Maximum inflow capacity in (MT) to the Telone process unit during period \( t \).

\( Q \) = storage capacity of one railcar (MT).

\( R_{\text{max}} \) = Maximum available railcars at side for shipping during period \( t \).

\( r \) = Costs of Capital rate per day.

\( R_{\text{max}} \) = Number of railcars available at the end of period \( t \).

\( T \) = Time period during period \( t \).

\( T_{\text{all}} \) = Maximum hours available for drumming during period \( t \).

\( V_{s} \) = Value of content of location "s" in (MT) during period \( t \).

\( X_{r} \) = forecast raw material from Allyl in (MT) during period \( t \).

\( Y \) = Telone Production yield.

\( Y_{s} \) = production Telone in (MT) during period \( t \).

\( Z_{s} \) = forecast Crude Telone volumes (MT) from Momentive during period \( t \).

Decision variables

\( A_{s} \) = Quantity of crude from the AV - 1008 telone that is going to the Telone process unit during period \( t \).

\( A_{\text{overmax}} \) = Allocated Telone II material to overseas during period \( t \).

\( A_{\text{bulk,EU}} \) = Allocated Telone II material for Bulk EU at period \( t \).

\( B_{1} \) = \[
1 & \text{if an overseas shipments has been made during period } t \\
0 & \text{else otherwise}
\]

\( B_{2} \) = \[
1 & \text{if Allyl material flows to the Telone process unit during period } t \\
0 & \text{else otherwise}
\]

\( B_{\text{railcar,s}} \) = Burning from railcar in MT during period \( t \).

\( B_{\text{vessel,s}} \) = Burning from Telone process unit in MT during period \( t \).

\( G_{1} \) = \[
1 & \text{if there is an stock -- out instance at the Truck loading station during period } t \\
0 & \text{else otherwise}
\]

\( K_{1} \) = \[
1 & \text{if there is an stock -- out instance at the Pape warehouse during period } t \\
0 & \text{else otherwise}
\]

\( N_{s} \) = (integer) quantity of railcars from Momentive to Stade storage Tank (AV - 1008) during period \( t \).

\( N_{s} \) = (integer) quantity of railcars from Stade to Botlek during period \( t \).

\( N_{s} \) = (integer) quantity of railcars from Momentive to TSS56 during period \( t \).
The objective function of this model is to maximize profit (function y). The objective function consist of turnovers (black brackets) generated by sales of Telone products and costs made within the Telone supply chain to make these products (red brackets).

**Sales**
The sales products that are included in this model are the drumming products, bulk products for the EU and overseas bulk products.

**Costs**
According to figure 15, there is one burning unit which can be used for burning crude or 1.3DCPE materials. For both of these burning flows equal burning costs holds. For the inventory holding costs of the storage tanks we have considered the content value of the different storage point multiplied by the opportunity costs of capital. In order to transport crude Telone material to Stade and finished Telone to the Botlek tank railcars are used. In this part we are only interested in the variable operational railcar shipment costs. Conversion costs are the variable production costs of the Telone process unit, which changes as the production volumes varies. Figure 15 shows how the conversion costs per MT vary with the production volumes. Higher production volumes results in a lower conversion costs per MT. However this relationship is not linear as can be seen from figure 15. A linear regression is performed on the historical conversion costs, based on this a linear function which approximates the conversion costs is developed. The following function is used in figure 15;

\[
f(Y_t) = Con - c * Y_t
\]

### Objective function

The objective function of this model is to maximize profit (function y). The objective function consist of turnovers (black brackets) generated by sales of Telone products and costs made within the Telone supply chain to make these products (red brackets).

\[
y = \left( \sum_{t=1}^{T} \sum_{i=1}^{T} P_{i,t} * All_{i,t} + \sum_{t=1}^{T} All_{oversea} * P_{oversea,t} + \sum_{t=1}^{T} All_{bulkEU} * P_{bulkEU,t} \right) - \left( Con - c * \sum_{t=1}^{T} Y_{t} \right) + \sum_{t=1}^{T} \sum_{i=1}^{T} V_{i,t} * r + \sum_{t=1}^{T} \sum_{i=1}^{T} B_{i,t} * B_{costs} + \sum_{t=1}^{T} \sum_{i=1}^{T} N_{i,t} * C_{railcar} \right)
\]

**Figure 15; conversion costs.**
7.7.7 Constraints

Mass balance constraints

\[ Z_t \leq l_t + e_t \quad \forall t(1) \]

\[ X_t = X_{1,t} + B_{z,t} + X_{z,t} \quad z = \text{Allyl}, \quad \forall t(2) \]

\[ Y_t = \left( C_1 \cdot A_t + C_2 \cdot X_{1,t} \right) \cdot Y \quad \forall t(3) \]

\[ Y_t = B_{z,t} + Y_{z,t} \quad z = \{\text{Telone process unit}\}, \quad \forall t(4) \]

\[ l_t = N_{1,t} \cdot Q \quad \forall t(5) \]

\[ d_t = N_{z,t} \cdot Q \quad \forall t(6) \]

\[ e_t = N_{3,t} \cdot Q \quad \forall t(7) \]

\[ f_t = N_{4,t} \cdot Q \quad \forall t(8) \]

\[ All_{i,t} = T_{\text{drumming},i} \cdot T \cdot All_{i,t} \quad \forall t(9) \]

Constraints (1) up to (9) are related to mass balance of the Telone supply chain flows. Constraint (1) relates to the number of railcars used to transport crude Telone from Momentive to Stade and to the T556 storage tank. The (2) second constraint relates to the mass balance of the Allyl crude Telone supply. The crude Telone supply from Allyl flows to the Telone process unit and to the burning unit. Next to this it is also possible that Allyl supply can flow to the AV-1008 storage tank. Constraint (3) relates to the inflow and outflow balance of the Telone process unit. The crude Telone that is flowing to the Telone process unit is a combination of crude Telone from Allyl and Momentive. At the Telone process stage, Telone material is extracted next to the lights and the heavies materials. Thus, material is lost and is dedicated to the lights and heavies. In order to relate the Crude Telone material that flows into the Telone process unit with the outflow of Telone material (1,3DPCE). This constraint indicates how much of crude Telone from Allyl and Momentive remains at the end of the Telone process stage. Therefore the crude Telone inflows are multiplied with constant values which indicates how much percentage is lost to the lights and the heavies. Next to this, the Telone outflow volumes is multiplied by the Telone process unit yield. Constraint (4) relates to the outflow mass balance of the Telone process unit. Telone that is flowing out of the Telone process unit goes either to the AV-1006 or to the burning unit. Constraint (5)-(8) relates to the railcar shipments. Constraint (9) relates to the drumming throughput capacity. The allocated Telone material for the drumming orders needs to be equal to the drumming capacity per order multiplied by the allocated drumming hours.

\[
\begin{align*}
INV_{end,t}^s &= INV_{end,t-1}^s + Z_{1,t} - \text{RailCars}_s + (N_{3,t} - \text{RailCars}_s \cdot Q) - A_t \quad s = \{AV - 1008\}, \quad \forall t(10) \\
INV_{end,t}^s &= INV_{end,t-1}^s + Y_{1,t} - (All_{1,t} + d_t + \text{BulkEU}_t) \quad s = \{AV - 1006\}, \quad \forall t(11) \\
INV_{end,t}^s &= INV_{end,t-1}^s + d_{1,t} - \text{Overseas}_t \quad s = \{\text{Botlek}\}, \quad \forall t(12) \\
INV_{end,t}^s &= INV_{end,t-1}^s + All_{1,t} - D_{1,t} \quad s = \{\text{Pape}\}, \quad \forall t(13) \\
INV_{end,t}^s &= INV_{end,t-1}^s + (N_{3,t} - \text{RailCars}_s \cdot Q) - (N_{4,t} \cdot Q) \quad s = \{T556 \text{ Botlek}\}, \quad \forall t(14)
\end{align*}
\]

Constraints (10)-(14) all relate to the mass balances of the intermediate storage tanks of the Telone supply chain. Restriction (10) relates to the inventory balance equation of the AV-1008 storage tank. Where the inventory level at the end of the period is equal to the inventory level of the previous day plus the inflow of Momentive supply minus the amount that flows to the Telone process unit. Constraint (11) relates to the mass balance of the Telone storage tank in Stade, there the inventory level at the end of the day is equal to the Telone level within the tank at the end of the previous day plus the material which is produced during
period $t$, minus the material that is allocated to drumming line, Bulk truck orders and the railcars that go to the Botlek tank. The mass balance of the Botlek tank (constraint 12) is such that the inventory of the Botlek tank at the end of the day needs to be equal as the inventory level of the previous day plus the railcar shipment that have been send 5 days ago from the Telone storage tank minus the allocated shipment to the overseas markets. The Pape storage point does not hold MTS orders instead drumming orders are kept over there before they are taken away by the logistic service providers at the same day. Constraint (13), which states that the inventory level of the Pape Warehouse at the end of the day needs to be equal to the inventory level of the previous plus the finished drum orders received during the day minus the orders that are shipped to the customers. The Autonomous supply of crude Telone from Momentive might also be shipped to T556 storage tank in Botlek. Constraint (14) indicates that the inventory level of the storage tank needs to be equal to the inventory level of the previous day plus the railcars that are directly received from Momentive minus the railcars that are sent to the Crude Telone storage tank in Stade (AV-1008).

**Capacity restriction**

$$X_{1,t} \leq X_t \quad \forall t \quad (15)$$

$$X_{2,t} \leq X_t \quad \forall t \quad (16)$$

$$B_{z,t} \leq X_{1,t} \quad \forall t \quad (17)$$

$$l_t \leq Z_t \quad \forall t \quad (18)$$

$$e_t \leq Z_t \quad \forall t \quad (19)$$

$$Y_{1,t} \leq Y_t \quad \forall t \quad (20)$$

$$B_{z,t} \leq Y_t \quad \forall t \quad (21)$$

Constraints (15)-(21) are implying that the different flow (decision) variables cannot be larger than what is forecasted at that particular day. Constraint (15) relates to the forecasted Allyl supply that is flowing to the Telone process unit, and states that this flow cannot be larger than the total crude that is supplied by Allyl during that day. Constraint (16) indicates that the Allyl flow to the AV-1008 storage tank cannot be more than the forecasted crude material from Allyl. Constraint (17) relates the Crude Telone flow that is going to the burning unit. For this, it is also not possible that this flow is larger than the available crude Telone supplied by Allyl. Constraint (18)-(19) are related to the Momentive crude material supply restrictions. Constraint (18), states that the Crude Telone supply from Momentive which is going to AV-1008 storage tank cannot be larger than the available crude Telone supply from Momentive. Similarly, constraint (19) states that the forecasted Momentive supply which is going to the T556 storage tank cannot be larger than the available Momentive supply during that day. Constraint (20) relates to the Telone (1.3DCPE) outflow of the Telone process unit, this flow cannot by larger than what is produced during that particular day. Similarly, constraint (21) states that the outflow from the Telone process unit that is going to the burning unit cannot be larger than the total produced quantity at that day.

$$P_{\min,t} \leq A_t + X_{1,t} \quad \forall t \quad (22)$$

$$A_t + X_{1,t} \leq P_{\max,t} \quad \forall t \quad (23)$$

$$A_{l,t} \leq D_{l,t} \quad \forall t \quad (24)$$

$$A_{bulkU,t} \leq D_{bulkU,t} \quad \forall t \quad (25)$$

$$A_{overseas,t} \leq M_1 \cdot B_{l,t} - l_{vessel,t} \quad \forall t \quad (26)$$

$$M_{in shipment,t} - A_{overseas,t} \leq M_1 \cdot (1 - B_{l,t} - l_{vessel,t}) \quad \forall t \quad (27)$$
Constraint (22) relates to the minimum inflow that is allowed to the Telone process unit. Whereas constraint (23) concerns the maximum inflow that is allowed to the Telone process unit. Constraint (24) states that the allocated Telone material for drumming needs to be smaller than the demand for the drumming products during a particular day. For the truck bulk orders constraint (25) states that the allocated Telone material cannot be larger than the truck bulk demand during the day. Constraint (26)-(27) are related to the overseas shipment from Botlek. If binary variable which indicates an overseas shipment (see constraints (26)-(27)) is equal to 1, then constraint (26) reduces to

\[ \text{All}_{\text{oversea},t} \leq (1000 = M_t) \]

Then respectively, constraint (27) also reduces to

\[ \text{Min}_{\text{shipment},t} - \text{All}_{\text{oversea},t} \leq 0 \]

Therefore, the allocated volume needs to be larger than Min_{shipment,L} and smaller than 1000 MT. If the binary variable is equal to 0, then constraint (26) reduces to

\[ \text{All}_{\text{oversea},t} \leq 0 \]

and respectively, constraint (27) also reduces to

\[ \text{Min}_{\text{shipment},t} - \text{All}_{\text{oversea},t} \leq 1000 \]

However, because of constraint (26) it is not possible to have an overseas allocation. Moreover, we have set the big M equal to 1000 as no shipment can be larger than 1000 MT.

Constraint (28) states that the allocated drumming order cannot be more than the available drumming capacity of the drumming line. Constraint (29) relates to the mix allowance of Momentive crude Telone and the Allyl crude Telone. This constraints sets a maximum limit on the inflow of Crude Telone from the AV-1008 (Momentive supply) storage tank. The inflow of crude Telone from the AV-1008 to the Telone process unit cannot be more than 40% (mix allowance) of the total crude Telone inflow to the Telone process unit.

\[ X_{1,t} + B_{2,t} \leq M_z \cdot B_t^2 \quad z = \{\text{Allyl}\}, \quad \forall t(31) \]

\[ X_{2,t} + B_{2,t} \leq M_z \cdot (1 - B_t^2) \quad z = \{\text{Allyl}\}, \quad \forall t(32) \]

In order to restrict the outflow from the Allyl process unit to either the Telone process unit or to the intermediate storage tank AV-1008 constraint (31)-(32) are added to the model. If the binary variable used for these constraints is equal to 1 then constraint (31) reduces to

\[ X_{1,t} + B_{2,t} \leq M_z \quad z = \{\text{Allyl}\} \]

And respectively constraint (32) reduces to

\[ X_{2,t} + B_{2,t} \leq 0 \quad z = \{\text{Allyl}\} \]

The same principle holds when the binary variable is equal to zero, then constraint (29) indicates that inflow to the Telone process unit needs to be smaller than 0 and the inflow to the AV-1008 storage tank needs to
be smaller than the big M (constraint (32)). The big M has been set for this case equal to the maximum production capacity of the Telone process unit. This because both flow cannot be larger than this.

**Storage restrictions**

\[ \text{INV}^s_{\text{end},t} \leq \text{Max cap}_s \quad \forall t(33) \]

\[ A_t \leq \text{INV}^s_{\text{end},t-1} \quad s = \{AV - 1008\}, \quad \forall t(34) \]

\[ (N_{4,t} \cdot Q) \leq \text{INV}^s_{\text{end},t-1} \quad s = \{T566\}, \quad \forall t(35) \]

\[ \text{All}_{l,t} \leq \text{INV}^s_{\text{end},t-1} \quad s = \{Pape\}, \quad \forall t(36) \]

\[ \left( \sum \text{All}_{l,t} + d_t + \text{All}_{\text{baikEU},t} \right) \leq \text{INV}^s_{\text{end},t-1} \quad s = \{AV - 1006\} \quad \forall t(37) \]

Constraints (33)-(37) all relate to the storage restriction of the intermediate storage tanks of the Telone supply chain. Constraint (33) indicates that the maximum allowed storage level for each storage tank. Constraint (34)-(37) are related to the capacity restriction regarding the outflow of the storage points.

**Railcar**

\[ \text{RailC}^h_{\text{end},t} = \text{RailC}^h_{\text{end},(t-1)} + N_{1,t} - l_{\text{railcar},t} - N_{1,t} \quad h = \{1\}, \quad \forall t(38) \]

\[ \text{RailC}^h_{\text{end},t} = \text{RailC}^h_{\text{end},(t-1)} + N_{2,t} - l_{\text{railcar},t} - N_{2,t} \quad h = \{2\}, \quad \forall t(39) \]

\[ \text{RailC}^h_{\text{end},t} = \text{RailC}^h_{\text{end},(t-1)} + N_{3,t} - l_{\text{railcar},t} - N_{3,t} \quad h = \{3\}, \quad \forall t(40) \]

\[ \text{RailC}^h_{\text{end},t} = \text{RailC}^h_{\text{end},(t-1)} + N_{4,t} - l_{\text{railcar},t} - N_{4,t} \quad h = \{4\}, \quad \forall t(41) \]

\[ \text{RailC}^h_{\text{end},t} \leq \text{RailC}^h_{\text{max}} \quad \forall t(42) \]

Constraint (38) up to (42) are related to railcars that are used to transport crude material from the Momentive supplier to Stade plant and from the Stade plant to the Botlek tank. Constraint (38) indicates that we cannot have more railcars at a particular period then the amount of railcars that were present at side at the end of the previous period plus the railcars that arrived to the site minus the railcars that departure to ship material. Constraint (42) relate to the maximum railcars that can be used for railcar shipments.

**OTS performance restriction Pape warehouse**

In order to oblige this model to have an OTS performance of 95% we have put a restriction on the Pape warehouse. This restriction is linked to the availability of products when needed at the Pape warehouse. Stock-outs at the Pape warehouse directly influences the OTS performance as products are not shipped on time. Therefore we have add the following restriction to the model:

\[ 0 \leq K_{l,t} + M \cdot K^1_{l,t} \quad \forall t(43) \]

\[ K_{l,t} \leq 0 + M \cdot (1 - K^1_{l,t}) \quad \forall t(44) \]

Where:

\[ K_{l,t} = D_{l,t} - \text{All}_{l,t} \quad \forall t(45) \]

\[ \frac{\sum \sum K^1_{l,t}}{T} \leq 1 - \text{OTS}_{d} \quad \forall t(46) \]

**OTS loading stations restriction**

Next to this, we also need to secure that the OTS performance of the loading stations for railcar and trucks is at least 0.95%. However, notice that the OTS performance is directly related to a stock-out instance. This
because all raw material used for drumming, and at the loading station is shipped at the same day. For this, we also have included the following constraints to the model;

**Truck loading station**

\[ 0 \leq G_t + M_3 \cdot G_t \]

\[ G_t \leq 0 + M_3 \cdot (1 - G_t) \]

**Where:**

\[ G_t = D_{buikeU,t} - All_{buikeU,t} \]

\[ \frac{\sum_{t'=1}^{T} G_{t'}}{T} \leq 1 - OTS_t \]

**Zero constraint**

For all of the decision variables we have formulated constraint (51), which indicates that these decision variables needs to be equal or larger than zero.

\[ T, All_{1,t}, A_t, X_{1,t}, X_{2,t}, N_{1,t}, N_{2,t}, N_{3,t}, All_{overseas,t}, Y_{1,t}, B_{x,t} \geq 0 \]
8) Verification and Validation
This chapter concerns the verification and validation of the mathematical model that is built for this project.

Tedeschi (2006) emphasizes that verification and validation of a model plays a crucial role in determining the usability of the model. Hamilton (1991) differentiates verification from validation as follows; verification is designed to ensure that a mathematical model performs as intended, while validation examines the broader question of whether the intended structure is appropriate. By this it is meant whether the model is an accurate representation of the system under study.

8.1) Verification
This model has been coded in the “OpenSolver” software; this software has its own model check for the consistency of the model in terms of variables and constraint definitions, linearity, and coding errors. Opensolver verifies the model each time the model is changed before solving the model. We also have checked the model outputs in order to see whether they are correct or not. Small recalculation of the model outputs have been performed after running the model.

Extreme value check
The mathematical model has also been checked for extreme values, these fundamental and primary checks help to see whether there are vital mistakes in the model. The model needs to pass these tests before performing the sensitivity analysis. For this part we have included the following situations; zero demand, zero costs, extremely high demand and extremely high costs.

Zero demand
If we set the demand (entire horizon) to zero the objective function is equal to the inventory holding costs, burning costs, railcar costs and conversion costs. As we expected no sales have been made by the model and therefore no positive profit. Because we deal with autonomous supply from our suppliers it is not possible to stock all these materials at the intermediate storage points T556 and AV-1008, therefore the model needs produce these raw materials into finished Telone and stock it at the AV-1006 and the botlek tank. Because of the limited capacities of these tanks it is even the case that the model burns Telone material.

Zero costs
If we set all the costs included in the model to zero the objective function is then a positive value. The model allocates enough material to serve all the demand, and overseas shipments are made when possible.

Extreme demand values
In order to see how the model behaves at extreme demand cases, the demand amounts have been set very high. The expected behavior is that the production needs to produce at its full capacity when there is enough raw material supply. Moreover, we also expect that there will be less overseas shipment as the model needs to allocate all the Telone products to the internal markets. From the model outputs, we have found that for extreme demand the model does not ship Telone material overseas. Moreover, no stock is kept at the T556 storage point instead all the stock is kept at the AV-1006. The utilization of the production and packaging and railcars used for crude material are very high. However, the production of the Telone process unit is limited by the availability of raw material supplied by the suppliers.

8.2) Validation
For the validation of this model we have performed sensitivity analysis and compared the outcomes of the model with real data.

8.2.1) Sensitivity analysis
After the extreme value checks have been performed and no unusual behavior is found, the model is tested whether it is behaving as expected in case when the input parameters are changed. The sensitivity analysis
have been conducted to see the impact of differences in single input parameters on the objective function. Furthermore, besides of the reliability of the model, this analysis will also provide insight about the important of the precision and value of these parameters are examined. Performing the sensitivity analysis with a rolling horizon is very time consuming, therefore we have left this out.

**Inventory holding costs**

In order to understand the behavior of the model when it comes to the inventory holding costs we have varied the costs of capital rate. Figure 16 shows the effect of the costs of capital on the total costs. From this overview we can see that changing the costs of capital results only in a linear increase of the inventory holding costs, all other costs components remained equal. Therefore, the total cost of the model increases equality as the inventory holding costs. This shows that the model output result is robust regarding changes in inventory holding costs.

**Figure 16; change in inventory holding costs.**

**Burning costs**

Figure 17 illustrates the effects of changing the burning costs on the model output. From figure 17 we can see that there are no burnings because of the zero burning costs. Therefore changing the burning costs does not affect the model output within this analysis.

**Figure 17; change in burning costs.**

**Railcars costs**

We also have performed a sensitivity analysis on the railcar costs, figure 18 shows the influence of changing the railcar operational costs on the total costs. As the operational costs of the railcars more stock is kept in
the intermediate storage tanks. Therefore the total costs increases as more stock is kept and the operational costs of railcars increases.

![Graph showing change in operational railcars costs.](image)

**Figure 18; change in operational railcars costs.**

**Conversion costs**

The conversion costs that is used for this model is a linear function which is an approximation of the actual conversion costs. However, it is interesting to know how the model reacts on conversion costs changes. Therefore 3 linear regressions have been used to see what the effects are on the model output (see appendix A7; linear regressions)

![Graph showing change in conversion costs.](image)

**Figure 19; change in conversion costs.**

From figure 19 it is shown that the model total costs increases similarly to the conversion costs change. From this analysis it turns out that the linear regression used is robust regarding the model outputs. Moreover, also the sales volumes remained equal for the different linear regressions.

**8.2.2) Evaluation Compared to Real Data**

Finally the model is validated by comparing the outcomes of the model to that of the year 2010. In this part we will handle the output of the model and compare that to the actual outcomes of 2010. Because of lack of actual data on some aspects of the model output we have also validated the model by experts within the Telone supply chain. The realized production figures and other important figures will always be different as the output of the model as we deal with an optimized model outputs. However, unexpected model outputs compared to the real data could be signs for a invalid model.

**Flow levels**

Figure 20 depicts the flow levels of the Telone supply chain, this concerns the Allyl raw material supply, raw material used from the AV-1008, Telone production levels, Allyl material in the AV-1008 and the burning...
levels. The total production level in 2010 of the Telone process unit equals to 13842 MT which is close to the real production level of 2010. Next to this, from figure 20 we also see that the production level of the Telone process unit is influenced by the Allyl supply and that the raw material from the AV-1008 tries to damp this behavior by making material available when there is not enough Allyl supply. From figure 20 it is also clear that in some instances no material is used from the AV-1008 storage tank, and because of this the Telone unit reduces its throughput. This throughput reduction is not caused by shortage of material or by full storage tanks. Because of the limited demand in these periods and the flexibility to allocate Telone material to the overseas market has caused that the production throughput is reduced. In real life, this is not the case as there is no synchronization of production and demand. Also from figure 20 we can see that there is no burning at all during 2010. This is also validated by the Telone supply chain production engineer.

Figure 20; flow levels.

**Overseas shipments**
From the model output figure 21 indicates the overseas shipments that have been made by the model regarding 2010. As the figure illustrate no shipment is lower than 500 MT. Moreover, we also do not have overseas shipments in the high seasons. This is also very logical as the internal demand within the high seasons is very high compared to the low season periods. In total the model has allocated 2879 MT to the overseas markets, this value is also considered as possible by experts from the Telone supply chain business.

Figure 21; shipments overseas.
Stock-outs

From figure 22 it is shown that allocating Telone material to the overseas markets does impact the stock-out instances at the internal markets. The model output of 2010 indicates that there are some stock-out instances for the Bulk Truck demand within the EU. This is mainly because the model has allocated a shipment in May this together with the high demand there was a very low inventory level in the period were the stock-outs appeared. The stock-out percentage of the model was 1.4%, this is also the OTS performance level of the Bulk truck orders.

![Stock-out Bulk EU](image)

**Figure 22; stock-outs Bulk EU (OTS failure).**

Inventory levels of the storage tanks

For the model outputs regarding the inventory levels of the storage tanks we have included figure 23. As this figure shows the inventory level of the AV-1006 starts very high, this because of the initial inventory levels that were present in 2010. Then this level reduces considerably as we continue in time. Next to this, we also see that no stock is kept at the T556 storage point at Botlek. Also, no stock is kept at the Botlek tank for overseas shipment in the high season periods.

![Inventory levels](image)

**Figure 23; inventory levels.**
Drumming line utilization

Figure 24 shows the model output of the utilization level of the drumming line. This figure illustrates that the utilization of the drumming line is going up in the high season periods and is low in the off-season periods.

![Drumming line utilization graph](image)

**Figure 24; drumming line utilization.**

Conclusion

The main conclusion that can be drawn from this validation process is there is a considerable increase in overseas shipments compared to the actual data. In 2010 there was in total 2300 MT shipped to the Botlek tank. However we do not know how much of this level went to the overseas markets. Our model allocates 2879 MT to the overseas markets which is an increase of approximately 25%. Moreover, from this analysis we also have found that there were no production losses. This is differently according the actual data for which there was an production loss of 401.5 MT. Next to this, we also suggest that because the model is shipping more Telone products overseas the average inventory levels needed to be reduced. However because of the lack of actual data regarding the average inventory levels per inventory point we could not compare the average inventory levels. The model also has a 1.4% stock-out (OTS failure percentage) this value is acceptable as the standard for OTS is to have at least OTS of 95%.

9) Scenario analysis

The analysis performed for verification and validation showed that the model is reliable and usable to make decisions regarding overseas shipments. Besides, the model can also be used to investigate the possible impacts of strategic decisions like increasing or decreasing the number of railcars, several demand scenarios.

However, in this report we only have included one scenario analysis which is a demand decrease from the internal markets. The main reason for this is to see what the effect of this scenario is on the Telone supply chain and how much do we allocate to the overseas markets.

Decrease of demand

When the demand is reduced by 50%, the overseas shipments increases to 9340 MT, this is far more than the amount which is allocated in 2010. On average there is also more demand at the Botlek compared with the model output of 2010. No stock was kept at the T556 storage tank upstream of the Telone supply chain. In this case also no stock-outs have been caused for the internal markets.

10) Software implementation

For the implementation of this model, one software package has been used. The main model is coded in OpenSolver software. OpenSolver is an Excel VBA add-in that extends Excel’s built-in Solver with a powerful and reliable solver. This software allows to have inputs from a excel spreadsheet and to the model is then solved and the outputs are exported to the excel spreadsheet. The data reported in excel by the model are easy to read, and all scenarios and runs that we have performed are solved within 564 sec.
In order to use the model we also have included a user guide manual which shows which data and how to run the model. For this we would like to refer to appendix A8 for the user guide of the inventory management (AV-1006) model.

11) Insights for managing AV-1006 storage tank
During the sensitivity and scenario analysis important insights for managing the Telone supply chain have been gained in addition to the further understanding of the proposed model. In this part the insights obtain from the sensitivity analysis will be formulated.

The sensitivity analysis revealed that the conversion costs are by far the largest costs component of the Telone supply chain. Because of this, the model always tries to increase its production output even when there is no demand from EU and when there is no flexibility in shipping it to overseas trade markets. However, because of high burning costs compared to the conversion costs the model always first tries to reduce its production rate in cases of a full storage tank (AV-1006) before burning any material.

Moreover, the starting inventory level of the AV-1006 is crucial when the model needs to determine the number of overseas shipments. The higher this starting level is the more overseas shipments are made. The model also has assigned 25% more material to the overseas markets than was actually done in 2010. Moreover, the model results also showed that no overflow instances at the AV-1006 intermediate storage tank. However, one needs to take into account the stock-out level of the internal markets when deciding to have an overseas shipment. From the analysis, we also have found that the T556 storage tank for crude Telone is not used by the model. For this, we question the usability of the storage tank as no crude Telone is kept in the T556 storage tank.
12) Conclusion

The initial aim of this study was to improve the On-Time Shipment performance of Dow AgroSciences (Telone Supply Chain). The On-Time Shipment performance measure of the Telone Supply chain performs under the business standard which indicates that the performance needs to be at least 95%.

After the orientation phase it became clear that the data concerning the On-Time Shipment performance could not be used as the starting point; this because of the lack and trustfulness in the data. This all has changed the direction of the study into evaluating the On-Time Shipment performance measure itself (policy). Based on the articles of C. Caplice and Y. Sheffi (1194) and A. Neely et al (1997) criteria were selected and used to evaluate the On-Time shipment performance measure of the Telone Supply chain.

We have found that the importance of the metric was not evenly distributed over all the involved parties. Dow AgroSciences is the owner of the Telone product but has outsources the production, packaging and some of the (planning and Scheduling activities) to other businesses within Dow (Dow chemical and BPSC). During our interview sessions we have discovered that the employees are not aware of the existence of the On-Time shipment performance measure. The main reason for this was that no agreements were made between Dow AgroSciences and the other parties regarding the level at which the outsourced activities needs to be performed. Therefore service agreements needs to be established between Dow AgroSciences and the involved parties. Service agreements needs to enable and enforce the involved parties to commit effort towards the On-Time Shipment performance. The current On-Time Shipment measurement process does not distinguish the performance of the different measurement points. Because of this, it is difficult to indicate what the contribution is of each measurement point. We highly recommend to keep separate On-Time Shipment performance scores for each measurement point. It also became clear that during the failure collection points responsible employees did not remember the causes for specific failures. Therefore, we would like to recommend that each failure in OTS performance needs to be documented at the end of a working day. One major issue of the On-Time Shipment performance measurement process is the lack of an improvement team which needs to address OTS failures. In order to have an effective improvement team which addresses failures, the right participants are needed to be included. For this we would like to add the following representatives; Scheduler drumming line, logistic service coordinator Bulk truck and the logistic service coordinator Bulk railcar to the S&OP supply meeting. At the supply meeting the On-Time Shipment performance will be discussed and failures are needed to be addressed. However, the On-Time Shipment failures for which extra resources are needed needs to be discussed at a higher hierarchical level of the S&OP meeting; A.I meeting. Failures that are unresolved at the supply meeting needs to be addressed at the A.I meeting. Also for the A.I meeting we would like to recommend to include the site logistic specialist or leader as they take decisions regarding extra resources. Moreover, reviewing the On-Time Shipment performance with the site logistic specialist or leader helps also to inform the specialist or leader about the performance of their employees regarding the On-Shipsments.

During the Orientation phase we have discovered that no formal inventory management policies where used within the Telone supply chain. Therefore, next to the initial On-Time Shipment assignment a second study “Inventory management” has been conducted within this report.

For the inventory management assignment, the lack of an inventory policy has resulted in production losses at the production stage of the Telone supply chain because of a full (AV-1006) intermediate storage tank.

Because of this a tool has been designed which needs to assist with making decision regarding overseas shipments. This tool consists of a Mixed Integer Liner programing (MILP) which uses “OpenSolver” as the software for solving the model. The software uses the excel format for input and output of the MILP model because of this it is easily to modify and to read the outcome results.

After modeling the problem and performing the validation steps, it has been concluded that the model is applicable for Dow AgroSciences to use for overseas shipments. Next to the overseas shipment, the model is also able to be used to conduct scenario analysis with different input parameters. Form this we could see
what the changes are on the model output results. The Model is not designed to use for daily operational scheduling or planning tasks of the production and the packaging stage. However it can be used to perform scenarios regarding the number of railcars needed and the effect of having different storage capacities. Moreover it also can be used to see effect of any further decrease in demand within Europe on the overseas shipments.

The model indicates that Dow AgroSciences could sent 25% more Telone material to the Overseas trade markets. Moreover, because of this no instances of overflows have been found in the model. The stock-out quantity of the model was 1,4% and is only observed for the Bulk orders within the Europe. Also the inventory level of the AV-1006 has been decreased considerable, however because of the shortage of data we cannot compare this with actual inventory level.

This study did not include supply of raw material from the external supplier as no forecasts are shared with the external supplier. Because of this we have assumed that there is ample supply of Momentive crude Material. Next to this, we also could not include capacity constraints on the burning units as no information was available about the capacity of the burning unit. This is also because multiple business are using the same burning unit and therefore indicating a feasible burning needs to be done by considering all other businesses. The same applies for the loading stations where multiple businesses make use of the same loading station. The effect of including the burning capacity and the loading station capacity might be that less material is removed from the AV-1006 storage tank and therefore the Telone unit needs to reduce its throughput. Including the burning and the loading station capacities will provide a more feasible model. Next to this, we also have limited our model to the botlek tank. However, it might turn out to be that there is no space available to stock the Telone material overseas. Having a broader scope which also includes storage tanks overseas would be a very interesting and valuable study for future researchers since this might provide a more reliable and robust plan for overseas shipments.

In literature there are only a few authors that have considered continuous production with a packaging stage. A couple of articles in literature address transfer a-synchronous line with non-general processing times. Next to this, there are also decomposition methods for these transfer lines that are separated with finite buffers. However these methods are only useful when looking for the steady state behavior of the system. A crucial point in analyzing systems in a long term behavior is that the initial inventory level is not relevant. This might be inappropriate when analyzing buffers in a short term horizon. A lot of mathematical models have been used in literature to address batch production systems with intermediate storage tanks. Most of the time, these models are used for scheduling and planning. The contribution of this study to the literature is that we have used methods that have been already tested in the batch industry the continuous process industries. Also this study contributes to literature by testing mathematical models to real life cases studies.
13) References


Tedeschi L.O. “Assessement of the adequacy of mathematical models” agricultural systems (2006); 89; p.225-247.
14) List of Abbreviations and definitions

DAS    Dow AgroSciences
OTS    On-Time Shipment
MRLs   Maximum residual levels
BPSC   Business process service centre
COPD   Customer Order Decoupling point
LSP=   Logistic Service Provider
RCU    regional Commercial Unit
GBU    Global Business Unit
MILP   Mixed Integer Linear Programming.
Appendix A1; S&OP meetings.

The Sales and Operations Planning process (S&OP) is the coordination and planning process of Dow AgroSciences on a tactical level. It begins with the Sales & Operations Planning at the regional Commercial Unit (RCU) level; this is then translated to the Global Business Unit (GBU) level and continues through to the final aggregated company plan that is approved at the Executive Sales and Operations Planning meeting. The S&OP process includes all plans (sales forecast, production plans, inventory plans, new product instructions and financial plans) and covers a current plus 2 year time horizon.

The Global S&OP process is conducted as a monthly cycle; it starts at the Regional Commercial Unit level, rolls up to the Global Business Unit level and finally to the overall executive DAS level.

The RCUs are focusing on a customers and GMIDs level. The Marketing specialist and/or Sales leaders create the Sales forecast as a part of the RCU S&OP cycle. At the GBU level the focus is more on molecules and assets. The GBU S&OP make decision on issues that are escalated by the RCU. The focus of the Executive S&OP is on priorities and resources. It sets annual targets, approvals overall financial and operational plans and resolves escalated cross RCU and cross GBU issues.

<table>
<thead>
<tr>
<th>1- RCU</th>
<th>2- GBL-GBU</th>
<th>3- Executive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers and GMIDS</td>
<td>Molecules and Assets</td>
<td>Priorities and Resources</td>
</tr>
</tbody>
</table>

- Creates and owns the RCU sales forecast
- Monitor progress on key operational and financial metrics for the RCU
- Decides and gives direction on issues escalated by the RCU’s
- Monitor progress on key operational and financial metrics for the molecule
- Sets annual targets and approve all plans
- Resolves escalated issues cross RCU and cross GBU
- Monitor progress on key operational and financial metrics cross GBU/cross RCU

Cross-functional Participation

As a standard part of the cycle, various appropriate metrics are reviewed, as well as determination and review of Root Cause investigations and Corrective and Preventive Actions (CAPAs). There is a cross functional participation from commercial, operations, supply and finance at each stage of the cycle.

Figure below shows the different meeting that take place during any given month. As is clear from figure below S&OP monthly cycle requires significant synchronization for all the RCU’s, GBU’s and the executive level. Next to this, it is also synchronized with the financial planning and reporting cycle.
The first meeting starting the S&OP cycle is the RCU demand Review meeting. The main focus is to review any significant changes to the RCU sales forecast, including a review of the key assumptions and upsides and downsides. The level of focus at this meeting is at actively managed GMIDS. The metrics reviewed in the demand review meeting are forecast accuracy and forecast bias. This meeting is led by the demand manager and includes key roles associated with sales forecasting; marketing specialist, sales leaders, key account managers, district sales managers.

The regional Supply Team meeting, that occurs between Day 7-8 basically focuses on understanding all the supply-related issues at the regional level; inventory strategy exceptions including safety stocks, on-time delivery logistics such as carrier performance, expectations to weeks of forward coverage, and others. They review the key metrics related to supply chain processes, Master Production Schedule performance, Distribution resource planning execution, Warehouse Inventory Record accuracy, as well as On time Shipment. These activities are facilitated by the Regional Supply Chain manager and include the regional Supply Chain related roles such as the Supply Chain Planning specialist, the Distribution Resource planner, logistics specialist and the detailed production specialist.

Based on the output of these first two RCU-level meetings, the demand Manager then facilitates the RCU Pre-S&OP meeting between Day 8-10.

The key focus for this meeting is to review exceptions from the Demand and Supply Review meetings and make needed decisions. Whatever cannot be resolved here is escalated to the next level. A review of key demand planning and inventory metrics takes place, as does a review of the action plans proposed to correct issues. The key participants in this meeting include; RCU leader, Marketing specialists, the RCU financial analyst, the Distribution resource planner, country sales managers, the supply chain planning specialist and Regional Supply chain Manager.

The last meeting held at the RCU level between Day 12-14th is the RCU S&OP meeting. This meeting is also facilitated by the demand manager and it is owned by the RCU leader. This meeting focuses on providing feedback on the decisions made at the pre-S&OP and ensures any resulting changes are incorporated into the RCU sales and financial forecasts. The RCU S&OP team also reviews other financial metrics such as contribution margins and sales ratios.

The first meeting at global Business Unit level is the Monthly Active Ingredient meeting held between Day 8-14th of the month. The key deliverables for this meeting are to establish a molecule production plan that is feasible and realistic. The participants identify issues that need to be escalated to the Global Business leader pre-S&OP meeting. The following metrics are reviewed at these meetings; Root cause investigations and Corrective and Preventive Actions. In this case the focus is on Produce to Plan (PTP) metrics and On Time Shipment for the relevant active ingredients. The Molecule supply chain Manager facilitates this meeting, which includes the Business line Manufacturing Representative, Active ingredient (A.I.) production coordinator and a number of site roles; site supply chain specialist or detailed production specialist, the site production leader, the site quality leader and the Site logistics specialists.

Based on the input from the Active Ingredient meeting and the RCU S&OP meetings, the GBL pre-S&OP meeting between Day 15-16 basically approves the global sales forecast roll-up for a molecule, and the supply /demand balances for the current year plus 2. This, where the global actions at the molecule level are defined. As with all other teams, metrics and Root cause Investigations (RCIs) and Corrective and Preventive Actions are reviewed. In these meeting, the focus is on the produce to plans metrics, Master production Schedule performance and On-Time Shipment for the active ingredients. The Molecule supply chain manager facilitates this meeting; other participants are the GBL, GBU financial analyst, the Business Manufacturing leader and the Market development manager or project success leader.

The last meeting at the Global Business unit level is the GBU S&OP that occurs between day 18-19. The key deliverables for these monthly meetings are to resolve issues escalated from all GBL Pre-S&OP meetings.
within the same GBU. They review the key financial forecasts, including sales, earnings before interest & Taxes and economic profit.

A summary of the cross-RCU forecasting metrics are reviewed, as well as On-Time shipment for the active ingredients, Produce to Plan and Master Production Schedule metrics. These meetings are facilitated by an assigned internal facilitator and owned by the respective GBU leader. The participants include the GBLs, the Molecule Supply Chain Managers, the GBU financial leader, the Business Operations Leader and the Supply Chain Leader.

Towards the end of each month (day 20-22th) the Dow AgroSciences S&OP meeting takes place. The key deliverables for these meeting are to approve the cross-GBU financial forecasts as well as the global inventory projections. This is also the committee that resolves any elevated cross-GBU and or cross RCU issues that are yet unresolved. This team also shares operational direction for the short and medium term with the key RCU and GBU & S&OP participants. The global corporate operational excellence metrics are reviewed at these meetings. This meeting is owned by Dow AgroSciences Chief Executive Officer or CEO. It is facilitated by the Global S&OP process Leader. All global commercial leaders participate, as the Global Financial Leader, the Global Operations leaders , Global R&D leader, Global Supply Chain Leader, S&OP Financial leader and the Global Corporate Affairs leader.

**S&OP meetings**

The S&OP meetings are conducted at several hierarchical levels; the Regional Commercial unit (RCU), the Global Business unit (GBU) and the executive level (see figure 9 for an overview of the S&OP meetings). In this part we will only focus on the Regional commercial unit level and the Global business unit level.

**Regional commercial unit**

The following meetings belong to the RCU level; demand review, Supply review, RCU-Pre S&OP and the RCU S&OP meeting. The first meeting of the S&OP meeting is the RCU demand review meeting. The main focus of this meeting is on the forecast. Significant changes in the forecast are discussed. Then the second meeting of the S&OP cycle is the regional supply team meeting. The focus of this meeting is on supply related issues at a regional level. Also at this meeting the OTS performance is for the first time reviewed (see the OTS performance review flow in figure 9). The employees that are included within this meeting are; Supply chain planning specialists, the distribution resource planner, logistics specialist and the detailed production specialist.
The aim of this meeting is to indicate and solve problems that are causing OTS failures. After this, the RCU pre S&OP meeting takes place. At this meeting exceptions from the demand and the supply meetings are reviewed and a decision is made. Whatever cannot be resolved at the Pre S&OP is escalated to the next level. The last meeting that is held at the RCU level is the RCU S&OP meeting. This meeting focuses on providing feedback on the decisions made at the pre S&OP meeting.

**Global business unit**

The first meeting at the global business unit level is the Monthly active ingredient (A.I) meeting. The key deliverable of this meeting is a molecule (multiple products) production plan that is feasible and realistic. The following participants are included within this meeting; Business line Manufacturing Reprehensive, Active ingredient production coordinator, site supply chain specialist, site production leader, site quality leader and the site logistics specialist.

The participants then determine issues which are needed to be escalated to the Global Business unit pre S&OP meeting. Based on the input of the Active ingredient meetings the RCU S&OP meeting takes place. At this point in time the global forecast, supply and demand for the current and next two years is approved. At this meeting the following participants are involved; Global business leader, GBU financial analyst, the Business Manufacturing leader, and the market development manager.

The last meeting at the GBU level is the GBU S&OP meeting. The key deliverables of this meeting is to resolve issues escalated from all GBL meetings. The following participants are included at this meeting; GBU leader, the molecule supply chain managers, GBU financial leader, the business operations leader and the supply chain leader.
Appendix A2; Supply chain coordination.
Appendix A3; OTS failure per packaging type & cause and effect diagram

Table below shows how the causes for the OTS misses are distributed over the different kinds of packaging types.

<table>
<thead>
<tr>
<th>Causes for delay or earliness</th>
<th>logistical service provider</th>
<th>Communications/ information flow</th>
<th>Internal capacity</th>
<th>Respecting work procedures</th>
<th>Unknown reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drums</td>
<td>13</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>81</td>
</tr>
<tr>
<td>Bulk truck</td>
<td>29</td>
<td>1</td>
<td>20</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Bulk Railcars</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>3</td>
<td>38</td>
<td>2</td>
<td>124</td>
</tr>
</tbody>
</table>

The cause and effect diagram in the figure below shows the logistic service providers, communication and information flow, capacity issues and unknown categories. Within each category the main causes for OTS failure are also included. Next to this, we also have included the On-Time delivery (OTD) performance measure in figure below to illustrate the effect the OTS might have on the OTD.
# Appendix A4; OTS performance format.

<table>
<thead>
<tr>
<th>Month</th>
<th>OTS active ingredient</th>
<th>OTS overall</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>February</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>March</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>April</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>May</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>June</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>July</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>August</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>September</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>October</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>November</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>December</td>
<td></td>
<td></td>
<td>95%</td>
</tr>
</tbody>
</table>

The first column relates to the Month of the year, the second column relates to the performance of that year for all measurement points. The third column contains the main comments on OTS defects (failures). Whereas Column 4 relates to the average performance of a particular month and the previous months of the same year. The last column indicates the targets of the Telone supply chain performance per month.
Appendix A5; Trend OTS Telone supply chain.

OTS performance trend Telone supply chain

OTS performance trend Pape warehouse
OTS performance trend Truck Bulk OTS performance trend railcar Bulk
Appendix A6; Criteria Performance measures

**Importance:** relate to the importance of a performance measure.

**Usefulness:** the usefulness of the performance measure; this relates to the usefulness of the data collected.

**Reactivity:** Relates to the measurement process of a performance measure.

**Robustness:** Relates to the degree the performance measure is interpreted similarly by the users, is comparable across time, location & organization and is repeatable.

**Level of Detail:** The degree to which the granularity or aggregation for the user.

**Validity:** relates to the accuracy of capturing the events and activities being measured and controls for any exogenous factors.

<table>
<thead>
<tr>
<th>Criteria’s for a good performance measure.</th>
<th>Articles</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance measure should be derived from strategy</td>
<td>Neely et al (1997)</td>
<td>Importance</td>
</tr>
<tr>
<td>Performance measure should be simple to understand</td>
<td>Neely et al (1997)</td>
<td>Usefulness</td>
</tr>
<tr>
<td>Performance measure should provide timely and accurate feedback</td>
<td>Neely et al (1997)</td>
<td>Reactiveness</td>
</tr>
<tr>
<td>Performance measure should be based on quantities that can be influenced, or controlled, by the user alone or in co-operation with others</td>
<td>Neely et al (1997)</td>
<td>Usefulness</td>
</tr>
<tr>
<td>Performance measure should relate to specific goals (targets)</td>
<td>Neely et al (1997)</td>
<td>Importance;</td>
</tr>
<tr>
<td>Performance measure should be part of a closed management loop</td>
<td>Neely et al (1997)</td>
<td>Reactiveness</td>
</tr>
<tr>
<td>Performance management should be focussed on improvements</td>
<td>Neely et al (1997)</td>
<td>Usefulness</td>
</tr>
<tr>
<td>Performance measurement should be consistent (such that it remains consistent as time goes by)</td>
<td>Neely et al (1997)</td>
<td>Robustness</td>
</tr>
<tr>
<td>Performance measurement should relay on explicitly defined formula and source of data</td>
<td>Neely et al (1997)</td>
<td>Robustness</td>
</tr>
<tr>
<td>Performance measure should employ ratios instead of absolute numbers</td>
<td>Neely et al (1997)</td>
<td>Robustness</td>
</tr>
<tr>
<td>Performance measure should be reported in a simple format</td>
<td>Neely et al (1997)</td>
<td>Usefulness</td>
</tr>
<tr>
<td>Performance measure should provide information</td>
<td>Neely et al (1997)</td>
<td>Usefulness</td>
</tr>
<tr>
<td>Performance measure should be objective instead of being based on opinion.</td>
<td>Neely et al (1997)</td>
<td>Validity</td>
</tr>
<tr>
<td>Does the metric provide guide for an action to be taken?</td>
<td>C. Caplice &amp; Y. Sheffi (1994)</td>
<td>Usefulness</td>
</tr>
<tr>
<td>Is the metric viewed and interpreted similarly by all affected parties?</td>
<td>C. Caplice &amp; Y. Sheffi (1994)</td>
<td>Validity</td>
</tr>
<tr>
<td>Is the metric simple and straightforward enough to be understood by those affected?</td>
<td>C. Caplice &amp; Y. Sheffi (1994)</td>
<td>Usefulness</td>
</tr>
<tr>
<td>Is the metric of a sufficient level of detail and precision for a decision maker?</td>
<td>C. Caplice &amp; Y. Sheffi (1994)</td>
<td>Level of Detail</td>
</tr>
</tbody>
</table>
Appendix A7; linear regressions

Linear regression (Conversion Costs)
Appendix A8; User Guide inventory management (AV-1006) model.

This part contains a user guide for the inventory management model designed for managing the intermediate storage tank (AV-1006). The input and output parameters of this model are structured in an excel spreadsheet which represent the user interface. Before solving the model one needs to install the OpenSolver software ([Download and Install](#)). Then extract the files from the .zip file, and double click on the OpenSolver.xlam file, this will open excel file and load OpenSolver. Once the inventory management model (AV-1006) is opened, there are two main frames; input interface and output interface. In order to solve the inventory management model (AV-1006), input data is needed. At this moment the needed input data is attached manually in the input interface of the model.

Input interface

In this part the input interface of the excel spreadsheet will be explained, this input interface is designed such that the model can extract the input data from this excel spreadsheet. For this, the excel spreadsheet contains a couple of columns which needs to be filled in before running the model. This input interface includes the demand and supply forecasts of (crude)Telone products, products sales prices, production capacities and the tank content values. Then there is also a table which contains the costs that are involved for solving the model. Each data set needs to be filled in at this moment manually at the right place.

**Demand and forecasts**

For the input interface of the Inventory management tool the following information is needed in order to solve the model; Demand forecast for the Bulk EU, Drumming orders (GMIDS). Supply forecast; Allyl supply, Momentive supply. For both the demand and supply data a horizon of at least 3 month is needed. This information needs to be added into the following columns of the excel spreadsheet below.

<table>
<thead>
<tr>
<th>Date</th>
<th>Forecast Allyl supply</th>
<th>Forecast Momentive supply</th>
<th>Demand forecasts Bulk EU</th>
<th>Demand forecasts Drumming orders (GMIDS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1-2023</td>
<td>306266</td>
<td>129690</td>
<td>212593</td>
<td>217907</td>
</tr>
<tr>
<td>2-1-2023</td>
<td>278649</td>
<td>212513</td>
<td>81538</td>
<td>17820</td>
</tr>
<tr>
<td>3-1-2023</td>
<td>229288</td>
<td>259093</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>4-1-2023</td>
<td>278650</td>
<td>268141</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>5-1-2023</td>
<td>201837</td>
<td>278650</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>6-1-2023</td>
<td>17827</td>
<td>201837</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>7-1-2023</td>
<td>21904</td>
<td>17827</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>8-1-2023</td>
<td>49013</td>
<td>17827</td>
<td>212513</td>
<td>81538</td>
</tr>
</tbody>
</table>

**Product sales prices**

For the sales prices of the Telone products included in this model the following columns needs to be used of the spreadsheet.

<table>
<thead>
<tr>
<th>Date</th>
<th>Sales price Bulk EU (MT)</th>
<th>Sales price Bulk overseas</th>
<th>Sales price Drumming orders (GMIDS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1-2023</td>
<td>20350</td>
<td>19000</td>
<td>212513</td>
</tr>
<tr>
<td>2-1-2023</td>
<td>23129</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>3-1-2023</td>
<td>217907</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>4-1-2023</td>
<td>221797</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>5-1-2023</td>
<td>217907</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>6-1-2023</td>
<td>217907</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>7-1-2023</td>
<td>217907</td>
<td>212513</td>
<td>81538</td>
</tr>
<tr>
<td>8-1-2023</td>
<td>217907</td>
<td>212513</td>
<td>81538</td>
</tr>
</tbody>
</table>

**Production capacities and value content storage tanks**

For the production capacity of the Telone process unit the following columns have been added to the input frame. Next to this, we also have the content value of the Inventory storage tanks.

<table>
<thead>
<tr>
<th>Date</th>
<th>Minimum inflow cap. Telone process unit</th>
<th>Maximum inflow capacity Telone process unit</th>
<th>Value of content inventory storage AV-1006 AV-1008 T556 Pape Botlek</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1-2023</td>
<td>306266</td>
<td>129690</td>
<td>212593</td>
</tr>
<tr>
<td>2-1-2023</td>
<td>278649</td>
<td>212513</td>
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<td>7-1-2023</td>
<td>21904</td>
<td>17827</td>
<td>212513</td>
</tr>
<tr>
<td>8-1-2023</td>
<td>49013</td>
<td>17827</td>
<td>212513</td>
</tr>
</tbody>
</table>
**Costs figures**

Table below shows the needed input parameters that do not fluctuate with time. For the first column (cell 2) the blending ratio of Crude Telone from Momentive and Crude Telone from Allyl needs to be filled in. Then, the burning costs of the burning unit needs to be filled in. Then the conversion costs intercept and sloop needs to be filled in. Then the variable operational costs needs to be filled in. The two factors which indicate the material loss fraction during the Telone process stage needs to be filled in below the variable operational costs of the railcar. Then, the costs of capital of the content value for the intermediate storage tanks needs to be filled in. The maximum drum capacity of the drumming line needs to be added into cell 9 of column 2. Then the Telone production yield of the Telone process unit needs to be added.

Next to this, we also need to fill-in the initial inventory levels of the intermediate storage tanks. Also the maximum storage capacities of the intermediate storage tanks needs to be added to this. The maximum available railcars for transporting crude or finished Telone needs also to be filled in.

<table>
<thead>
<tr>
<th>Blending ratio</th>
<th>Starting Inventory levels (t-1)</th>
<th>Max storage capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV-1008</td>
<td>T556</td>
<td>Botlek</td>
</tr>
<tr>
<td>AV-1006</td>
<td>Botlek</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Max available railcars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentive-------AV-1008</td>
</tr>
<tr>
<td>Momentive--------T556</td>
</tr>
<tr>
<td>T556--------AV-1008</td>
</tr>
<tr>
<td>AV-1006--------Botlek</td>
</tr>
</tbody>
</table>

Once all the input data is placed at the right location of the excel spreadsheet, Opensolver solve option can be turned on.

After pressing the Opensolver solve option button, OpenSolver analysis your spreadsheet to extract the optimization model which is then written to a file and passed to the CBC optimization engine to solve. When errors are found in the model a dialog box is displayed which indicates the type of errors that are in the model. The result is then read in, and automatically loaded back into your spreadsheet. The model output data contains a lot of information, our output interface only includes the following information; performance measures, costs components, sales volumes, railcar operations, inventory levels, and if there needs to be an overseas shipment.

**Output interface**

Once the model is solved OpenSolver will then automatically load the solutions into the output (spreadsheet). Instead showing all the output data to the users we have chosen to concentrate on the overseas shipments as this is the main aim of this study. Figure ,,,, below shows the model output interface which the user will come across when using the model. The output interface contains also a VBA run and clear all button, for running and clearing the field such that new output can be placed. Moreover, the output also contains the performance measures that are included in the model; stock-out, overflow and On-Time Shipment. Next to this, the costs component of the model are also included in the model output interface.
The model output interface also shows the inventory levels of the different stock points of the Telone supply chain. It is also possible to see from the interface how many railcars are in use within the Telone supply chain. In order to know if there is an overseas shipment needed we also have included an overseas shipment cell which indicates if there needs to be an overseas shipment or not. The decision for an overseas shipments needs to be taken one month before the actual shipment date. So if we have a “Yes” answer in the following cell then this means that we need to arrange an overseas shipment.