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Increased capacity through load chart scheduling based on standardization of long-cycle manual work

Master's thesis in the master's programme Production Engineering

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Department of Materials and Manufacturing Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
39 products scheduled for production by two operators per shift in P3 charging department. The production on dissolvers four and five is the same as for the three sample weeks, see Figures 22, 23 and 24, except the production has been compressed into only one week instead of three.

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ABSTRACT

This master's thesis project has been carried out at the AkzoNobel International Paint factory in Angered, Sweden. The purpose of this thesis has been to increase the capacity at the factory's P3 pan charging department and to improve the weekly charging schedule by calculating ideal lead times for the most frequently produced products.

Due to the large product range (around 130 different products), product lead times were not measured from start to end. Instead all possible work tasks used to manufacture the different products were identified in order to set a standard time for each work task. The work tasks were then combined into a sequence using the unique work order for each product. The work tasks and their sequences were created in the software AviX, which summarized the standard times for all work tasks into complete lead times for each product. Each work task's standard time was established either by direct time study measurements, usage of the SAM predetermined time system in AviX or a combination of the two. Most of the data collection for the work tasks was done using a video camera.

In total 70 product lead times were created in AviX, which historically covers 93.4 percent of the production in the P3 pan charging department. Each lead time was visualized by a so-called scheduling bar divided into different colors, which represented different types of times, such as machine times and time for manual work. These scheduling bars were then used in a new load chart scheduling system created in Microsoft Visio. The result indicates that using this scheduling system could on average give an increased capacity of more than 120 percent. The capacity increase can be used to assure that the weekly volume demand is always met. It will also free up time to work with continuous improvements and 5S as well as time for training of the charging personnel.

Keywords: Chemical industry, Paint manufacturing, Functional layout, AviX, Lead times, Production capacity, Production scheduling, Gantt load chart, Man-machine chart, Standardization, Predetermined time systems, Time study

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CONTENTS

1. Introduction

This chapter gives an introduction to the subject of the thesis and also explains the production process that has been studied.

1.1. International Paint

The protective marine coating brand International was introduced by two brothers Max and Albert Holzapfel after they in 1881 decided to become successful in the marine coating market. This became the starting point for the International Paint company that today is recognized worldwide and a member of the AkzoNobel group (Wood (2009)). International Paint has over 5500 employees and is currently operating in 60 countries (AkzoNobel (2014) About International). Their market is divided into three main units – Marine Coatings, Protective Coatings and Yacht Coatings – which are all producing different kinds of products within their market area (AkzoNobel (2014) Our Markets). Felling in England serves as International's main operational base (Wood (2009)). However it is in their only factory in Sweden, located in Angered outside Gothenburg this master thesis has been carried out.

1.1.1. Angered factory

The Angered plant has about 156 employees and delivers their coatings to the European and the African market. Typical uses of the paint produced at the factory in Angered are in big steel constructions like bridges, airports and sports arenas. Their products are engineered to protect against rust and in the best possible way withstand fire in case of a fire outbreak (Utveckling Nordost (2012)).

The production area in the factory is divided into three departments titled P1, P2 and P3, where each department is divided into two sub-departments labeled charging and filling. The charging area is where all products are produced and the filling area is where each product is filled into varying sizes of buckets and drums. Besides charging and filling, there are also two smaller pre-batching areas, one for liquids and one for powders.

1.1.2. P3 charging department

P3 is the smallest department in terms of output volume but has the highest variety of products. The products produced at P3 can either be bases or hardeners. The department is also responsible for production of so-called stainers which are classed as intermediate goods and used as raw material in the commercial paints. A paint at P3 is composed by a mixture of different powders and liquids. The products at P3 are signified by long and varying lead times which means the cycle in which work tasks are carried out is also long. The different paints and coatings at P3 are produced by mixing raw materials using either a stirrer, a dissolver with a fixed tank or a dissolver with a mobile pan. This thesis project has only concerned the four dissolvers with mobile pans. The volume capacity range for these four dissolvers is between 600 liters and 1000 liters per batch, depending on the size of the pan used. Each work day is divided into two work shifts with two operators at each shift.

1.1.3. The production flow at P3 charging department

The charging process at P3 can, simplified, be divided into five different phases – charging preparations, liquid charging, powder charging, dispersion and quality assurance (see Figure 1). Liquid charging, powder charging and dispersion are phases in the manufacturing process that could occur numerous of times or not at all when producing one product. However these phases are just represented once in Figure 1 to make the picture more comprehensible.

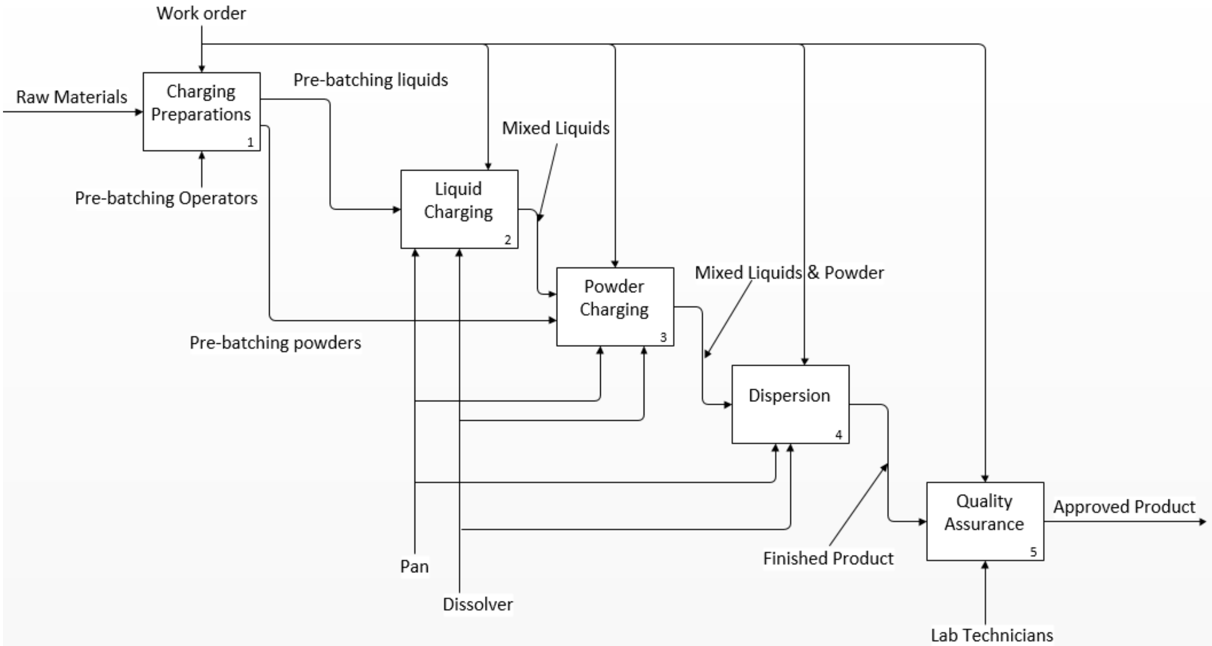

Figure 1 – IDEF0 process map of the P3 charging department.

Figure 1 gives a simplified picture of the process flow for producing one product at P3. There are five boxes representing one production phase each. The arrow that goes into each phase from the left is the input (what to be transformed during the phase), the arrow that comes out from the phase is the result of the transformation, the arrow from above is what is controlling the phase (in terms of time and work execution) and the arrow from below describes the mechanisms required to be able to perform the transformation in each phase.

For the charging preparations phase there is one operator working with pre-batching of powders and one with pre-batching of liquids. These operators are delivering pre-batched raw materials to all three departments in the factory. The pre-batching should be completed before the charging operator starts the charging procedure. What raw materials that are to be pre-batched is specified on the products' work order.

A work order is a description of which raw materials a certain paint consists of and in which order they should be charged. It works very much like a baking recipe and the work order is often referred to as the recipe among the charging personnel, but in this report it will only be referred to as the work order. Each paint product has a unique work order however many similarities can be found when comparing similar paints. A work order also specifies temperatures and grinds which have to be achieved during the charging process. Most machine times are specified on a work order as well as which day the charging of the product should start and when it is due for delivery.

During the liquid charging phase pre-batched liquids are fetched with a forklift from the pre-batching storage and thereafter charged into the pan. A pan is like a cylindrical container, which can be moved with the assistance of a forklift. The largest pans have a volume of about 1000 liters and the smallest can contain about 200 liters. Not all liquids specified on the work order are pre-batched as some are available via manifolds, which is a tap station from which commonly used liquids can be charged. Each manifold is connected through pipes to different tanks, outside the factory, containing the different liquids and is equipped with a counter where the requested amount of liquid can be specified. When the counter is started a pump connected to the selected tank is activated and starts to pump liquid from the tank through the pipes, via the manifold counter and into a pan. When the counter reaches zero the pump is automatically deactivated. After a manifold has been used it is necessary to clean the used pipes by a procedure called pigging. When performing the pigging procedure a rubber plug is shot through the pipes using compressed air and the remaining liquid is forced through the pipe system. This ensures that all of the liquid ends up in the pan and that liquids do not mix inside the pipe system. Those liquids that are not pre-weighed must be weighed by the charging operator into either a bucket, a small 200 liter pan or directly into the pan after it has been connected to a dissolver.

A dissolver is a type of machine which main function is to mix all the raw materials and grind down powder particles into a specified size. The dissolvers this project have been concerning consists of a dissolver lid which prevents the paint from splashing, a rotating blade that mixes the raw materials and grinds powder particles and a pan which can be moved in under and out from the dissolver lid using a forklift. The blade gets its rotating power from the dissolver engine. Figure 2 displays one of the dissolvers studied in this thesis.

Figure 2 – Dissolver with and without a pan installed.

The powder charging phase is very similar to the liquid charging phase, but instead of charging liquids different powders are charged. Contrary to the liquids, the charging operator rarely needs to weigh the powder raw material, since it is mostly supplied in bags of specified weight.

After powders and liquids are mixed together it is common with a dispersion phase which is a process performed by a dissolver or a bead mill and aims to diminish the size of the powder particles in order to achieve a certain grind. The grind is specified on the work order and states the powder particle size requirement for each paint. The size range of the particles can be from five micrometers up to over 100 micrometers. For the dissolvers it is the rotating blade that shreds the powder particles into smaller elements. Sometimes the dissolver blade is not powerful enough if an extra fine grind is to be achieved. It is then necessary to use a bead mill.

A bead mill pumps the paint from a pan into a small rotating chamber filled with glass beads where the powder particles are grinded into smaller elements by the friction between the glass beads and the paint. After the paint has passed through the chamber it will end up in an empty pan. There are two old bead mills (bead mill eleven and bead mill eighteen) used in the P3 department for grinding all colored paints, except white and light grey. The bead mills have several variable factors that can all contribute to their performance when grinding. Despite this they are poorly equipped and there are only indicators for paint temperature and pressure inside the bead mill chamber. Besides these two bead mills there is also the so-called Cosmo bead mill, which is used only for white, light grey and non-pigmented products. The products running through the Cosmo bead mill are usually thinner and contain either no pigments or just a small amount. The Cosmo does not use glass beads like the older bead mills but rather beads of another ceramic material. After the paint has run through the Cosmo it is directed back into the same pan from which it first came in a process called recirculation.

When all specified liquids and powders have been charged, the specified grind has been achieved and the product is complete according to the work order a quality check is mandatory (see Figure 1). The quality control is performed by a lab technician who receives a quality sample from the charging operator together with its related work order. If the sample is not approved an adjustment of the corresponding batch will be necessary. It is then necessary to adjust the paint through the addition of some extra raw materials in order to get it approved for filling. What raw materials that need to be added are specified on an adjustment note from the quality department.

1.1.4. The weekly charging schedule at P3 charging department

To fully understand the complex process of how a weekly charging schedule is being made at P3 is a difficult task. However it is important to have an overall comprehension of this process to understand this report.

The weekly charging schedule is based on the yearly volume plan which is made in International Paint's headquarters in Felling. The yearly volume plan is based on a forecast analysis of the demand from the market. The production planner at the Angered factory receives the yearly volume plan divided into twelve monthly volume plans, which then are divided into weekly volume plans. At this state it is only established how many liters to produce for a certain week. The weekly volume is then divided between the three charging departments. To make the actual production schedule for each department the production planner uses an Enterprise Resource Planning system called MFG/Pro which delivers the volume demand for each product. The data delivered from MFG/Pro is based on four factors; volume in stock, forecasts, customer orders and volume level indicators in different storages which gives a signal to the business system to produce more of a specific product. With this data and the weekly volume demand a rudimentary production schedule is established. This basic production schedule is just a list that specifies what product to produce, what volume to produce of each product, which day to start production of each product and which dissolver that should be used. The production schedule for P3 is then received by a charging operator from the same department. The charging operator converts the production schedule from a list into a table format (see Figure 3). Each product is labeled with a product code consisting of three capitals and three digits and the last four digits of the work order number. The production plan may later on during a week be changed due to different circumstances such as delays, adjustments and a shortage of raw materials.

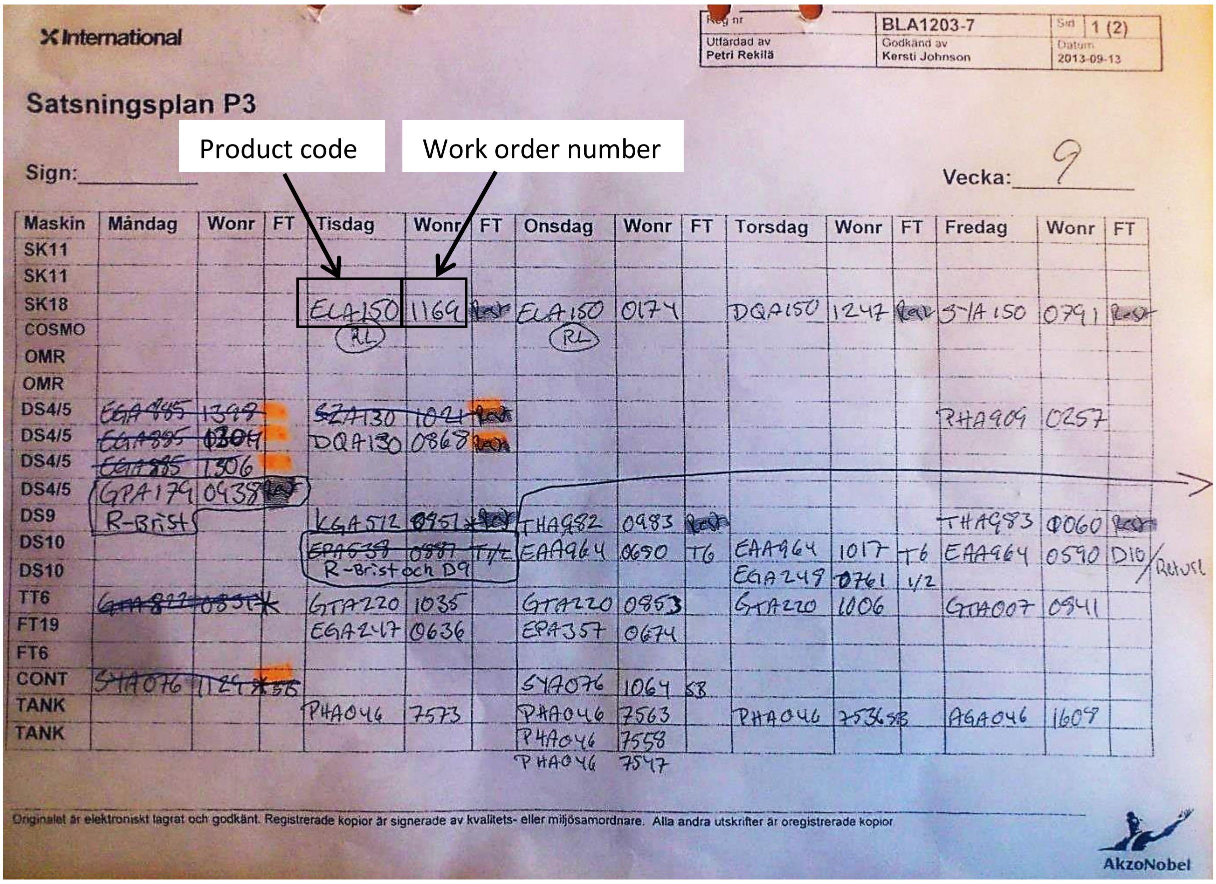

Figure 3 – Example of weekly charging plan at P3.

1.2. Project background

International Paint aims to remain a world class paint manufacturer and is therefore continuously improving their organization at different levels. Since the Angered factory is a big part of International Paint the goals are shared and the factory works according to the whole company's principles. P3 charging department has been struggling with a low accuracy in its weekly charging schedule which has sometimes affected its delivery accuracy to the customer in a negative way. One reason for the low accuracy could be due to that the charging schedule is created based on the operators' experience rather than any established lead time for each product. At the same time an increased demand from the market puts an increased output demand on each department in the factory. A change is therefore required in order to continue to be a world class paint manufacturer.

1.2.1. Project purpose

The purposes of the study are to increase the capacity and productivity at P3 charging department and to improve the weekly charging schedule by calculating ideal lead times for the most frequently produced products at dissolvers four, five, seven and seventeen. These purposes have to be fulfilled while keeping or improving the current work environment.

1.2.2. Objectives

To deliver a suggestion of standardized work procedures, a documentation of standard lead times for all delimited products and a new scheduling system.

1.2.3. Research questions

The following research questions will be answered in this thesis:

- How can capacity be increased using only available resources?
- Is it possible to establish standard times for long-cycle work, when there is a big product range?

1.2.4. Boundaries

The study will consider only the most frequent products that are routed through dissolvers four, five, seven and seventeen at the P3 charging department. It was decided that only the products produced in an average of two or more times annually the past four years should be taken into consideration for the study, due to the limited amount of time (see Figure 4). There were 61 different products with that historical production rate, four of which were stainers. The studied lead times will be defined as starting from the moment an operator fetches a pan (in which the product is produced) up to the moment a quality sample is delivered to the quality inspection with complete documentation.

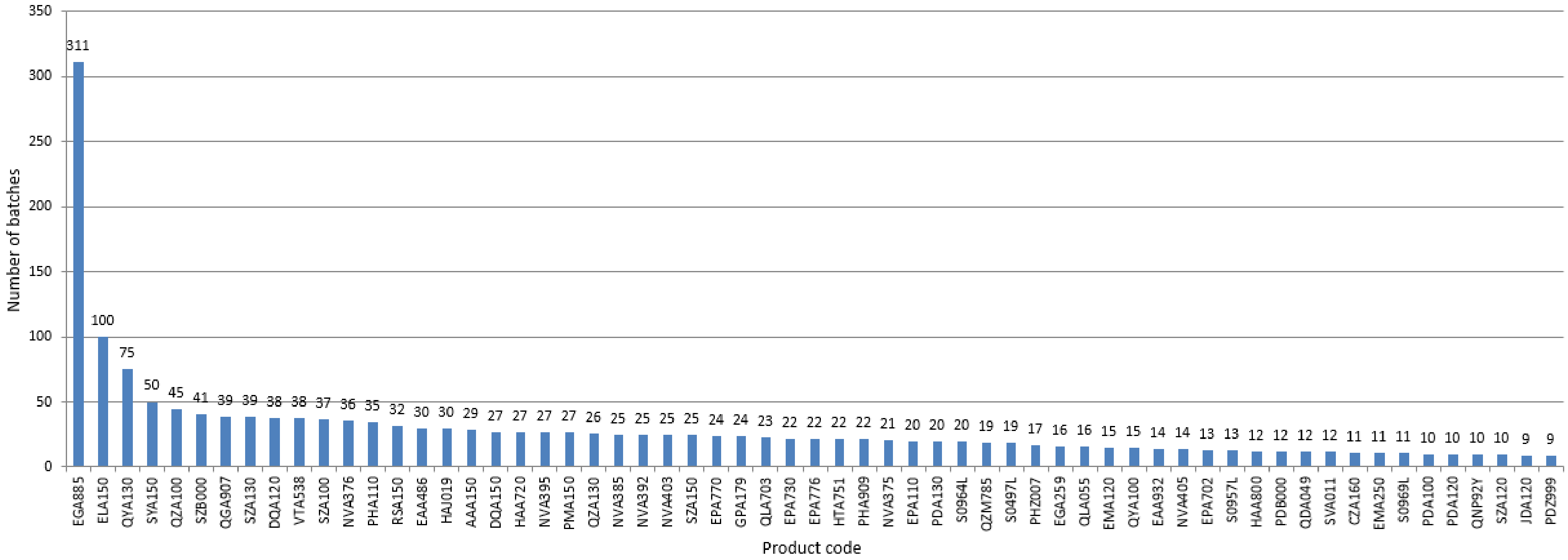

Figure 4 – Number of batches produced the past four years for the most frequent products at P3 charging department.

2. Theory

In this chapter the underlying theories behind the tools and methods used in this thesis are described.

2.1. Increasing production capacity

Commonly, production capacity is increased by investing in new resources and according to Levinson (2007) it is important to elevate the bottleneck of the production process in order to increase capacity. Investments that can increase capacity are for example new or improved machines or hiring additional operators. But capacity can also be increased with only the available resources.

The term capacity can be explained as the potential maximum output a factory or a resource can produce during a time period. This description of capacity links it to production productivity, since productivity is, according to Almström (2013), defined as output over input. If productivity is increased it will be possible to produce the same output in less time which results in a potential maximum output (capacity) increase. Almström (2013) explains that productivity can be improved focusing on three factors – Method (M), Performance (P) and Utilization (U). The following equation presents the relations between productivity and its three factors (Almström (2013)):

$$Productivity = M * P * U$$

The method factor represents the method used for manual work or the method used for a machine operation. The performance factor is the working pace of an operator relative to the idle cycle time. Further on the performance factor can be divided into two sub-factors – personal performance rate and skill based performance rate, where the impact of these factors depends on the individual's physical attributes and skill level. The utilization factor can also be divided into two sub-factors – need based utilization and system design utilization, where the first mentioned factor is dependent on personal needs and the second factor is based on system design losses like, for example, balancing losses (Almström (2013)).

2.2. Performance rate

Performance rate is the rate at which a worker executes a task. A 100 percent performance rate, or standard rate, is usually attributed to that of an experienced worker working at a sustainable rate and experiencing no excessive fatigue provided the appropriate rests are taken. Because of this, it is favorable to use such a worker when performing time studies and avoiding too slow or too fast workers. An experienced worker has been defined as one who uses smooth and consistent movement with a rhythm, has a short response time to signals, can anticipate difficulties ahead of time and works in a relaxed almost subconscious manner. The rating of work performance is still a subjective decision that has to be taken by the observer although there are some common accepted examples of standard rates, like dealing a pack of 52 playing cards in 22.5 seconds (Kanawaty (1992)).

2.3. SAM

SAM, short for Sequential Activity and Methods Analysis, is a tool that is used for three main purposes (MTM-föreningen i Norden (2004)):

- The design of new work methods, or improvement of existing ones, to achieve as optimal productivity as possible.
- The documentation of work methods in order to achieve the same outcome every time an activity is performed.
- The setting of standard times for the documented work tasks.

Within Swedish industry there is an agreement between companies and unions that the work times stated by a certified SAM-analyst are approved as a foundation for setting standard times for different work tasks.

2.3.1. Predetermined time systems

A Predetermined Time System (PTS) is a device preferably used to remove any subjectivity, on the observer's part, when performing normal time studies such as what skill level the studied operators have, what performance rate is held, selection of standard times and how to deal with deviations (Smith (2001)), (Maynard, Stegemerten & Schwab (1948)).

SAM is a PTS and is based on the Methods-Time Measurement (now commonly known as MTM-1) developed in the 1940's by Maynard, Stegemerten and Schwab (Aft (2001)). In the MTM-1 system the standard times were set for very basic human motions, such as reaching, grasping and turning the hand. Although a PTS, some subjectivity is still inherent in the MTM-1 standard times since they are based on standard rates, though this subjectivity has been minimized through the usage of several independent subjects (Sakamoto (2010)). In the SAM system these basic motions have been combined into a sequence of motions constituting an activity. All SAM activities are presented in *Table 1*. One example could be the Get activity which is one of SAM's most basic activities. The Get activity is built up by a reach and a grasp and later on also a release motion (MTM-föreningen i Norden (2004)). This means SAM is more coarse than MTM-1 but it also means that a SAM analysis can be carried out in much less time (ViPP Guide 1.2 – Man in the virtual factory (2014)). In SAM the basic time unit is not seconds but rather a unit called factors. One factor is defined as five Time Measurement Units (TMU) (MTM-föreningen i Norden (2004)). A TMU, in turn, is defined as 36 milliseconds, making 100,000 TMU's equal to an hour (Maynard, Stegemerten & Schwab (1948)).

Basic activities	Supplementary activities	Repetitive activities
Get	Apply force	Screw
Put	Step	Crank
	Bend	To and from
	Lifting heavy objects	Hammer
		Read
		Note
		Press button

Table 1 – SAM-activities

2.4. Standardization

In the Lean-philosophy the purpose of standards is stated to be the foundation for all continuous improvements or as it is called – kaizen. This means that without any standards there will be no maintainable improvements. The improvements made without any standard stated will not work, because it is impossible to say if the randomness from the unstandardized work was improved or if just another way of performing a specific task was added (Liker & Meier (2006)). Standardized labor has its origin from Fredrick W. Taylor who made a great effort to standardize different work tasks and measure standard times for them (Bishop (2001)). Over the years this type of scientific approach has received a negative tone in the industry. However the fact still remains that without a standardized work method, which is measured to take a certain time, it is tough to make a good and accurate schedule (Bishop (2001)). Standardized work methods are not only beneficial for the management in a company. If the measurement of the standardized work task is properly performed it will be beneficial for the employees as well, because the expectations from the company will be clearly stated. With standard times for different work tasks it will be easy to calculate what is expected from each employee to produce, which will remove any anxiety from the employees regarding their performance level (Bishop (2001)).

2.4.1. Setting standard times

When developing standard times it is vital to consider the cycle time for the operation that is to be standardized. Depending on the length of the cycle time there are different measurement approaches which are suitable to use (Smith (2001)). Smith (2001) divides work into short, medium and long cycle times. Short cycle times are defined as up to 20 seconds long and highly repetitive and often performed in a limited area with most of the required equipment within arm's reach. Medium cycle times are in the range of 20 seconds to 20 minutes and can involve several work stations and may or may not involve repetitive work tasks. Long cycle times are in the range of 20 minutes to 1000 hours or more and often contain long distances between different work areas (Smith (2001)).

Work within the range of short cycle times are preferably measured with direct measurements. Direct measurements implies that the measured time for a certain action is only used for that specific action and are not to be reused in any other operation (Smith (2001)).

For work classified as medium cycles, standard data is a suitable method to use. Standard data elements are composed by well-defined sub-activities, which should be adjusted to the specific work task regarding size, content and number of sub-activities used (Smith (2001)). According to Connors (2001) standard data sub-activities can exist in different levels where in the lowest level a sub-activity typically is represented by a few fundamental motions performed by a human. Each sub-activity represents a standard time, which either could be measured with a measurement tool or stated by a PTS (Connors (2001)). Work belonging to the longest cycle time category has a third approach when it comes to stating standard times. For this kind of work a PTS is a suitable tool to use (Smith (2001)).

2.4.2. 5S

Liker & Meier (2006) describes 5S as a useful tool for eliminating waste connected to unnecessary movements and searching for equipment. The 5S tool is divided into five steps labeled as: Sort, Straighten, Shine, Standardize and Sustain (Liker & Meier (2006)).

According to Peterson & Smith (1998) each step can be explained as follows:

Sort **–** During this step all equipment that are being used in a specific work area should be identified and sorted in a frequency order. Equipment that are not being used should be sorted out.

Straighten **–** All equipment should be placed in the frequency order that was decided upon in the previous step. This means that the most frequently used tool should have the most accessible location in that area.

Shine **–** Besides cleaning, this step is about continuous control and assessment of the work area in order to maintain safety, order and routine maintenance.

Standardize **–** Standardize all 5S activities and make everyone agree upon the standards in order to maintain order and cleanliness at the work area. The standardization should be documented and visualized in the work area in question.

Sustain **–** During this step three main activities should be performed: conduct a visual assessment, develop an improvement plan and assure that everyone involved has a responsibility in order to sustain all standards created during the 5S procedure.

5S can be described as a cyclic process and is meant to be used frequently in order to assess each standard and continue to develop them into better procedures.

2.5. Allowances

During a shift, an operator cannot be expected to work a hundred percent of the time. Various eventualities causes the operator to shift attention to some other task or to stop working entirely. Examples of such eventualities are rests, toilet breaks, conversations with colleagues or going on any recognized break like breakfast or lunch. With the exception of recognized breaks, a goal should always be to reduce non-productive time. This means that these times should not be accounted for when standardizing the work. But since personal needs cannot be eliminated it has been common in many organizations to add a so-called allowance time, typically about five percent to base times, to absorb any disturbances to productivity that occur due to them. Depending on the physical demand of the work, another minimum allowance of five percent is usually added because of an operator’s need to rest. A further allowance of between one and five percent is commonly applied to any delays the operator might experience that is the result of factors that the operator cannot directly influence, such as management or planning errors (Allerton (2001)).

2.6. Production capacity scheduling

International Paint uses an overall strategy for planning called Enterprise Resource Planning (ERP) at the macro level. ERP uses a combination of models for the finances, sales, manufacturing, logistics and human resources of the whole enterprise to create an information system for the organization (Schtub (1999)). Due to the scale of this information system ERP requires a high computational capacity. One product of International Paint's ERP system is the production plans upon which each week's production schedule is based.

2.6.1. Plan versus schedule

There are a number of differences between a plan and a schedule. Firstly, a plan shows what is desired of the production while a schedule shows what the production can actually produce. Secondly, a plan may not pay any concern to capacity while a schedule will only be useful if it does so. Thirdly, a plan may be fashioned for a single order while a schedule has to take all orders within its timeframe into consideration (Lankford (2001)).

2.6.2. Finite and infinite loading

In literature, two of the most commonly discussed strategies for capacity scheduling are so-called finite and infinite resource loading. Finite loading means that the planner heeds the resource capacity when constructing the production schedule. This means that any jobs that make the resource exceed its set capacity will be rejected. When the planner instead chooses to load a resource without any regard to its capacity the infinite loading strategy is being used. This strategy is most applicable when the amount of jobs taken on is variable and uncontrolled (Hendry & Kingsman (1989)). One common term when planning using infinite loading is Capacity Resource Planning (CRP). But when creating detailed production schedules infinite loading and CRP will not do the job. Instead, so-called Finite-Capacity Scheduling (FCS) should be used. Depending on the complexity of the production system, however, a lot of computational power may be required in order to generate an optimized schedule based on FCS. FCS is therefore best done on a computer (Lankford (2001)).

2.6.3. Gantt load chart

One way to visualize a production schedule with a finite loading strategy is a Gantt load chart (Lopez & Roubellat (2009), Aswathappa & Shridhara (2010)). In a Gantt load chart the planned time that a job spends at a resource is displayed as a bar or block. If the resource can only handle one product at a time the blocks should be graphically wide enough to hinder any other jobs from being scheduled for that resource, see Figure 5. The time of day that a job is scheduled to be started and finished is displayed on the horizontal axis.

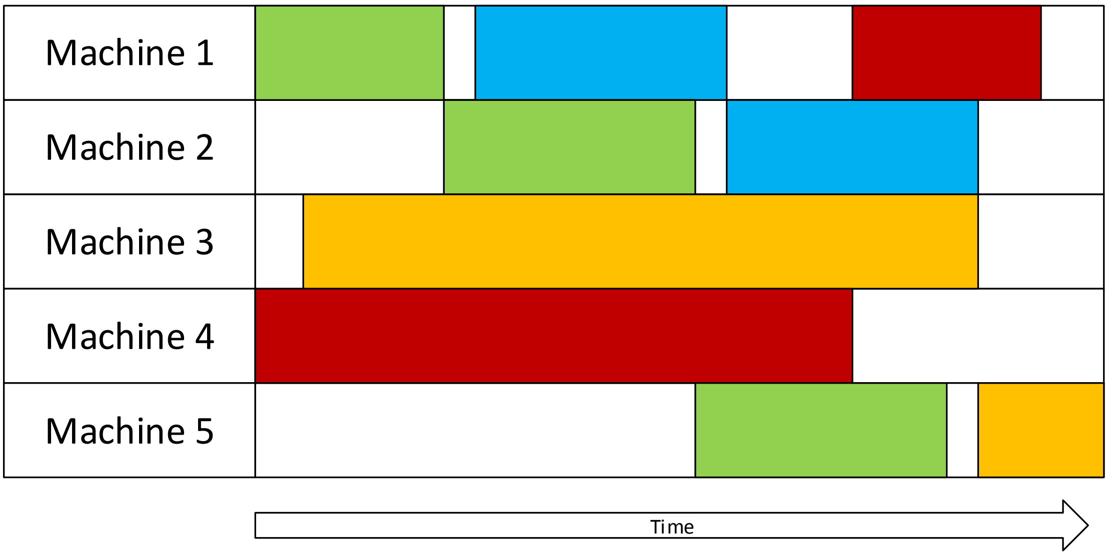

Figure 5 – Gantt load chart.

2.6.4. Man-machine chart

A man-machine chart details how operator working times and machine times are distributed and how they interact with each other. It can be used as an analysis tool for visualizing interferences between the machines' and the operators' working cycles. The chart features three defined activities: independent work, combined work and waiting. Independent work is when either the operator or the machine is performing work without assistance from the other. Combined work is when the operator and the machine are both busy with the same operation which as an example could be when the machine is being set up by the operator. Waiting occurs when the machine or the operator has to wait for the other before being able to proceed with the next task. The man-machine chart is usually aligned vertically (see Figure 6) and the time axis starts at zero to better visualize how much time each task requires (Loch & Smith (2001)).

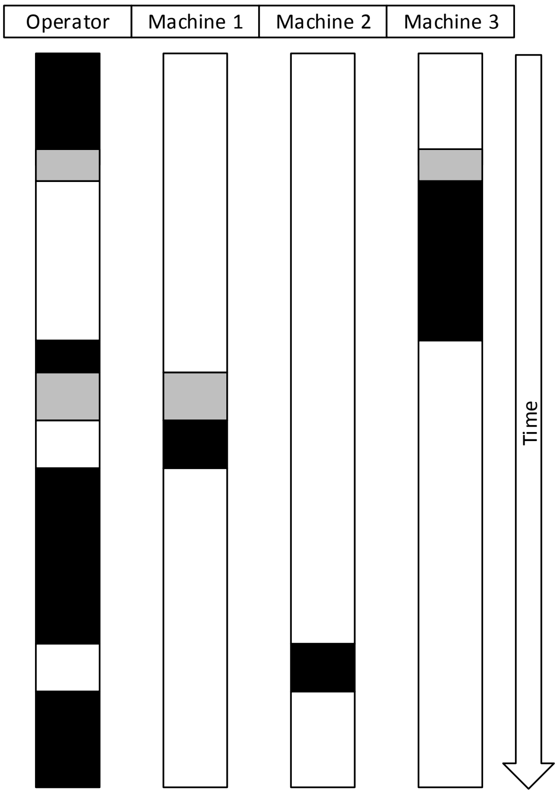

Figure 6 – Simple man-machine chart. Black represents independent work, grey represents combined work and white represents waiting.

2.7. External and internal work

During the 1980s Shigeo Shingo of Toyota developed a method for decreasing changeover times in production that came to be called Single Minute Exchange of Dies (SMED). Since then the method has been adopted on a global scale. Perhaps the most important part of the SMED methodology is the categorization of external and internal work. External work is of such nature that it can be performed while the line or machine is operating. Internal work on the other hand is carried out only when the line or machine has been stopped (Henry (2013)). In order to decrease machine downtimes, it is easy to understand that converting internal work to external work should be the main point of focus. But external and internal work does not necessarily have to relate to changeovers. When unrelated to changeovers and SMED, internal and external work are usually referred to as direct work and indirect work respectively. Direct work then becomes work that is required and contributes to the product's lead time while indirect work is required but does not contribute. These definitions are also distinguished from the activities of the man-machine chart which all contribute to the product's lead time.

2.8. Time study

The stop watch time study was first used and developed by Frederick W. Taylor more than 100 years ago. Since then the method has been applied worldwide. During the decades the equipment used for time studies have been digitalized and computerized, but the time study procedure and definition remains the same (Sellie (2001)). Sellie (2001) has the following definition of a time study: "*Time study is a procedure used to measure the time required by a qualified operator working at the normal performance level to perform a given task in* *accordance with a specified method*". When performing a time study a video camera is preferably used, due to the increased accuracy of the time study and lesser skill requirement of the analyst (Akiyama & Kamata (2001)).

Before a time study can start it is necessary to do a method analysis to see if the best possible method is used to perform a certain work task. With the best standardized work method established, an operator which masters the work method has to be selected for the study. It is also important that the operator work pace not varies more than plus or minus 25 percent of the standard performance rate. Equally important is it to select the right operator and to inform the operator and the team leader about all details concerning the time study. The time study analyst must be honest and answer truthfully to all questions regarding the time study. If this is done in a proper way it will prevent conflicts further on in the time study (Sellie (2001)).

Sellie (2001) also describes the importance of dividing the operator's work into smaller elements in order to enhance the accuracy of the time study. Each element should represent a certain work task composed by one or several fundamental body movements. An element could also represent different machine processes or activities used by the studied operator. All elements should be predefined with a starting point and an endpoint. Besides increasing the accuracy of the time study the usage of elements will foster future improvements of the standardized work procedure (Sellie (2001)).

2.9. AviX Method

AviX Method (henceforth referred to as just AviX), from Solme AB, is a software with several different applications for manufacturing industry and in particular industries who rely heavily on manual work (Solme (2014)). Among many other functions AviX contains a SAM analysis tool. This tool allows the user to efficiently perform a SAM analysis while at the same time having a video clip of the task that the analysis is focused on as support. AviX can also be used to rather accurately determine times that cannot be acquired through a SAM analysis. AviX uses the MTM-SAM standard times for its analysis tool which means that the base time unit is factors. AviX also translates the factors into time in seconds with one decimal point.

3. Method

This chapter describes the procedures for the studies that were made on the factory floor as well as those used when composing the product lead times and creating the new planning system.

3.1. General approach

Because the P3 department was known to have a wide product range there was a realization that not all products would be available for studying during the project's course, despite the delimitations. However, it was also known that the work procedure for charging the different products is roughly the same. Since every product has its own work order and all work orders were available at request the decision was made to focus on individual work tasks instead of the product lead times as wholes. To avoid the inclusion of unwanted disturbances when determining the times for the work tasks the utilization of MTM standard times was necessary. This set the modularization[1] level to that of basic human moves and in turn necessitated a SAM analysis. When the work tasks had been analyzed, their times could be combined, with the assistance of the work orders, to build up the complete product lead times. The lead times were then to be used in creating the new weekly scheduling system. To summarize, the course of the project can be divided up into four parts, shown in Figure 7.

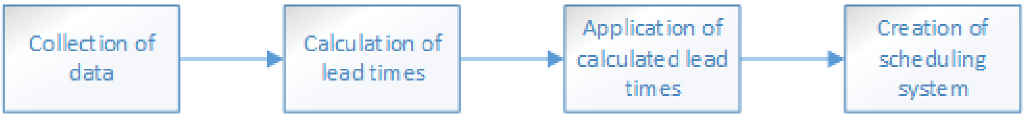

Figure 7 – General approach for the project.

3.2. Collection of data

Although the authors of this thesis had gained valuable experience from the P3 production department prior to starting this project there was a need for collecting data for all the unknown factors that are involved when charging a product. The collected data was inserted into a database that in the end contained all the values that were necessary to build up the work activities.

3.2.1. Capturing film

Most of the data collection was carried out on the production floor by recording the various work tasks with a handheld cam recorder. The idea was to document every possible work task that an operator is required to perform when charging a product. The operators filmed were considered to work at the standard performance rate. If there were any disturbances to the operators' work while filming these would be subtracted upon analysis of the video. Important factors, other than the work tasks, were also captured on film such as various

[1] Modularization refers to the creation of modules. A module in this context is the base level from which the times are built up.

machine constants. These films were used to determine manifold pumping, and other machine related, speeds.

3.2.2. Measuring bead mills

Prior to this project there were no data on how long a batch would take to complete a bead mill run and this time was thought to vary a lot since the operators manually had to fine tune the mills' pumping speed. Since it was already known that the bead mills constitute the bottleneck in the charging, and in extension the whole production, the quantification of their throughput times was a main point of the project's focus and was mandatory in order to establish complete lead times. Before being able to measure the times on the old bead mills (eleven and eighteen) it was decided that the operators would need to adopt a standardized working procedure when handling these bead mills. This new procedure was discussed with the operators and, despite the fear that it would require more work, was agreed upon and measurements could then be done using the speed of the flow of paint coming out of the bead mill. Two different measuring methods were used. In the first, the flow speed was determined by clocking the time it took for the paint to fill a half-liter measure and then doubling that time to get the flow in seconds per liter. Using the volumes of the raw materials specified on the work order a throughput time, in seconds, could be calculated using:

$$Throughput\ time = Speed\ of\ flow * Total\ volume\ of\ paint$$

The second method was to measure the level of paint in the pan at time t_0. As soon as the measurement had been done a timer was started. At a later, arbitrary time t_1 the level of paint in the pan would be measured again to find out how much it had risen during the given time. The inner diameter of the pan also had to be measured to be able to know what volume of paint had flowed into the pan during the time between t_0 and t_1. The volume of paint was obtained using the formula for a cylinder's volume:

$$Volume\ of\ paint = \left(\frac{Inner\ diameter}{2}\right)^2 * (Height\ at\ t_1 - Height\ at\ t_0)$$

When the speed of flow was known the time could be calculated using the same formula as for method one.

The number of laps that the various products had to go through the bead mill was also important to know. During the measurements a grind check was therefore done either by an operator or by a technician at the lab. One grind check was done for each lap the paint was transferred through the bead mill until the grind was approved and the product was cleared for post-charging. The paint would then have to finish the lap it was currently on before it could be disconnected from the mill.

Measurements on the Cosmo bead mill were done differently. Because the Cosmo bead mill is usually run with paints of a relatively low viscosity, low volume and high speed of flow the throughput time for one batch is often less than 30 minutes. It is therefore easier to pump the paint through the bead mill and then back into the same pan (recirculation process). This is done until the grind is checked and approved. Because of this different procedure the measuring method used for the old bead mills cannot be applied here. Instead the time of day for starting each batch on the Cosmo was written down on the work order. As soon as the grind was approved the time of day was noted again and the Cosmo running time could be calculated.

3.2.3. Temperature and dispersion times

In addition to the bead mill times there were also other machine times on the work order that were unknown. These times appear when either the grind of the paint has to reach a certain specified fineness or the temperature of the paint has to be raised or lowered to a certain value or interval. These times were not actively measured since they can be several hours long but instead the operators were handed the task to, like on the Cosmo, note the time of the day that the dissolver was started and the time that it was stopped. If there were any stoppages during the machine time these would be subtracted from the final time.

3.2.4. Categorizing powders and liquids

Different powders have different characteristics that affect the charging time. Powders are, for safety reasons, charged through a grate into the dissolver. This results in there being a distinction between different powders' ability to flow through the grate. Many powders will “saturate” the grate and instead of running through the grate they form a mound that rests on top of it. When this happens a brush must be used to get all of the powder into the dissolver and this brushing time is another time that varies depending on the powder charged. Moreover, the powder bags are of different volumes and weights and there is also a difference in just the speed that the powder flows out of the bag. The P3 charging department alone uses several hundred different raw materials, many of which are powders, rarely used (and could thus not be observed during the project’s limited timeframe) and some of which are not regularly to be found in the raw material storage. This created a need for making some assumptions and simplifications regarding their charging times and characteristics. Powders were categorized into five different categories where the categories represented different powder characteristics. If a powder was encountered on a work order and had not been observed by the authors of this project a categorization was performed by asking experienced operators or by examining the size, weight and compactness of the powder bags in the storage. Some powders could also be related to similar, known powders and be categorized that way.

The liquids were split into two different categories. As with the powders, the two categories pertained to the speed of charging, although this time from a bucket and in the case of fluids this speed ultimately relates mostly to the viscosity (Von Mises & Friedrichs (1971)). But in addition to this the categories were also based on if scraping had to be done by the operator to completely empty a bucket. The categorization was performed by observing the various fluids either in the production or in the raw material storage.

3.2.5. Measuring distances

Since the different stations in the production are spread out in the factory there were a lot of walking and driving distances that had to be measured. The walking distances were measured simply by counting the number of steps to get from one point to another. This was carried out either actively on the factory floor or by analyzing films that had been recorded. Calculation of steps was a viable method of measuring because there are standard times in MTM for them. The driving distances were timed using a stopwatch and more than one sample was often taken. If there occurred any unexpected obstacles when timing a driving distance that sample would be discarded and a new one had to be taken. This was to ensure that the measured times were as ideal as possible. The final time would then be the average of the recorded samples.

3.3. Calculation of lead times

Aside from just calculating a product's time from beginning to end, one main idea when calculating the lead times was to know a number of other times as well. These were:

1. Dissolver machine time.
2. Bead mill machine time.
3. Time that the operator spends on a product outside machine time (direct work).
4. Time that the operator spends on a product during machine time (indirect work).

Work could in this project be split up into two parts; required work that adds to the lead time (direct) and required work that does not add to the lead time (indirect). If required work does not add to the lead time it is performed in parallel to some other function that takes a longer time, usually a machine time. The time used for performing required work tasks during machine time is of interest since they show how much time an operator has available for breaks or for performing other tasks, unrelated to the product. Even though the bead mill times are technically machine times they were kept separate from the dissolver machine times in an attempt to visualize their particular length and show that they indeed constitute the bottleneck.

3.3.1. Construction of lead times

First of all a lead time in this thesis was defined as starting from the moment an operator fetches a pan and ending when the operator leaves a quality sample with complete documentation. The basis for calculating the lead times was essentially to calculate the time needed for every single work task involved between those two points. The calculated times were set to become the standard times for the work tasks. This also meant that the work procedure chosen for each work task should not compromise quality and safety. To calculate the standard times a combination of SAM analyses and measured times were used. As more and more work tasks were calculated they could be combined to build up the complete products, as described by their work orders. It became necessary to create libraries in which all constructed work tasks were placed. Since most of the work tasks for dissolvers four and five could not be used for dissolvers seven and seventeen two libraries were created to minimize searching time for a specific work task and to avoid the risk that a work task was used for the wrong set of dissolvers. All this work was done entirely in AviX. A small snippet from the list of work tasks in the library for dissolvers four and five is depicted in Figure 8. The level of the different work tasks was divided into three categories (short, medium long and long) depending on the length of the work task. The standard times established for short work tasks were often done by direct measurements usually with the assistance of a video camera. Some work tasks belonging to the short category were later used when creating the medium long and long work tasks. The medium long work tasks could either consist of just SAM analyses or a combination of SAM analyses and short categorized work tasks. A similar division was made when constructing the long work tasks but instead of just reusing a combination of short work tasks and SAM analyses medium long work tasks were also added when creating the long work tasks, see Figure 9.

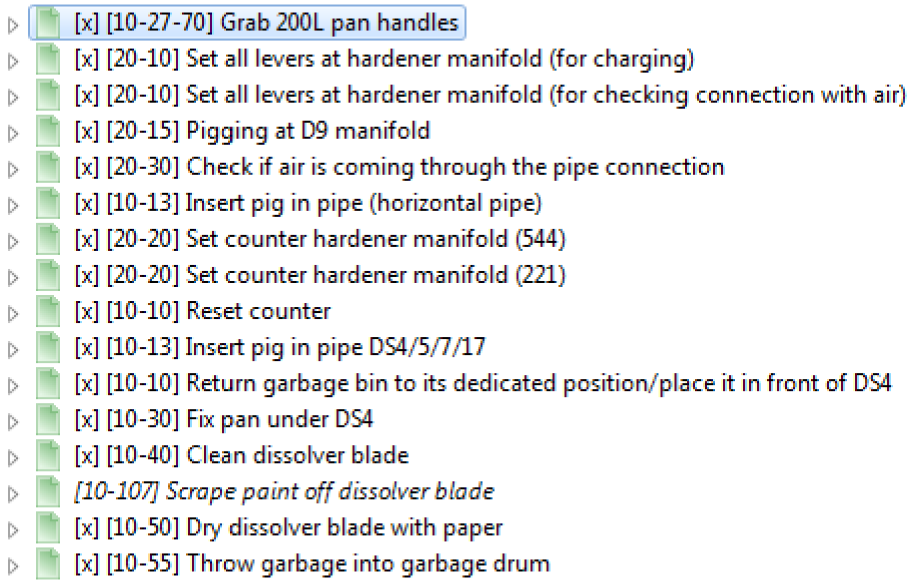

Figure 8 – Snippet from the list of work tasks in the library. The numbers are used by AviX in a reference system and have no meaning for the work tasks.

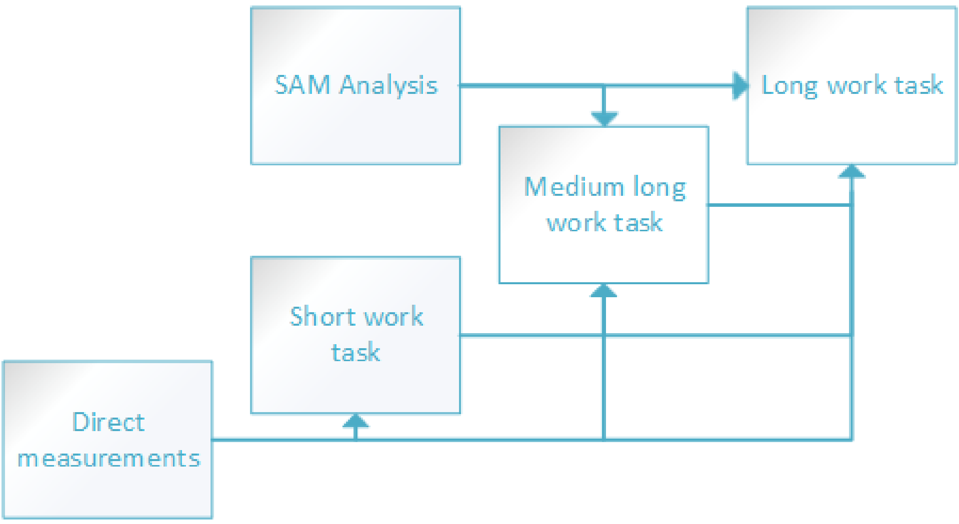

Figure 9 – How the different work tasks were built up in AviX.

AviX also allows the user to choose which activities should be classified as value adding, necessary or non-value adding. This function was utilized to separate machine times from work tasks and also to differentiate between the tasks that are performed during machine time and those that are performed outside of machine time.

3.3.2. Work classification

There are five colors available for work classification in AviX. In this thesis, green represented the total dissolver machine time for a product while orange represented the bead mill machine time, like in chart B in Figure 10. Yellow represented the amount of indirect work. Because AviX automatically determines walking to be non-value adding it assigns the color red to such activities. This means that all walking will be presented as red unless the user manually chooses to change the classification to another color. If an activity is not walking and not otherwise classified by the user it will have the default color grey. When constructing the lead times in AviX, the work classification of all direct tasks was left unchanged which meant that they would be either red or grey. Subsequently the direct time would be the sum of the red and the grey times. Most products had a similar time distribution to chart A in Figure 10.

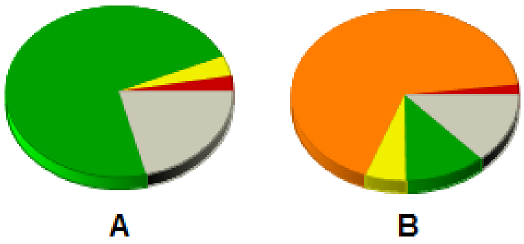

Figure 10 – Color representation in AviX. Green is total machine time while yellow is indirect work. Grey and red together represent direct work.

4. Results

In this chapter the results on the lead times, live implementation tests, work standards as well as the new digital production scheduling system are presented.

4.1. Powders and liquids

When the data collection was completed 34 different powders had been filmed and had their charging time measured. 25 of these times were averages based on four samples or more. 18 more unobserved powders were categorized and depending on the category were assigned one of the values in Table 2. These values are average times from all the measured powders in each category for the two sets of dissolvers. Some unobserved powders were deemed so similar to an observed powder that they were instead assigned the average charging time for that observed powder.

Category	1	2	3	4	5	<40 % weight
Average time [s] dissolvers 4 & 5	6.74	9.43	15.71	45.40	86.81	11.55
Average time [s] dissolvers 7 & 17	5.40	10.67	20.35	46.67	147.40	11.55
Brushing time [s]	13.19	17.90	17.00	19.52	41.13	13.19
Brushing rate	Once after charging all bags	Once after charging all bags	After every bag	After every bag	After every bag	Not required unless charged alone

Table 2 – Powder categories.

Table 2 also shows that if a pre-batched powder bag contained less than 40 percent of the original weight a different average time was used. For reasons of simplification, this average time was considered to hold true regardless of the powder categories.

In addition to the powders, 41 liquids from buckets or jerry cans, eleven liquids from drums or containers and 18 liquids from manifolds had been categorized. For the buckets and jerry cans there were only two categories and they did not differ between the two sets of dissolvers as the powders did. The liquid categorization is shown in Table 3. For simplification, a cutoff point was set at seven liters of liquid, since it was around that level of volume that a sharp increase in pouring time was observed.

Category	1	2
Average time [s] <7 liters	2.8	2.8
Average time [s] >7 liters	5.4	7.0
Scraping time [s]	Not required	47.8

Table 3 – Liquid categories from buckets.

When charging liquids from a drum the charging time was separated into two stages. The first stage was when the liquid was flowing out of the drum at full speed. The second stage was the runoff stage when the drum was more or less empty. The total charging time was the sum of the time for these two stages. Three categories were used as shown in Table 4.

Category	1	2	3
Time at full speed [s]	82.9	154.0	293.0
Runoff time [s]	47.7	80.3	121.0
Total time [s]	130.6	234.3	414.0

Table 4 – Liquid categories from drums.

For complete lists of the measured times for all powders and liquids, as well as other times, see Appendix D.

4.2. Machine times

The new standard working procedure for bead mills eleven and eighteen that was adopted is shown in Figure 11.

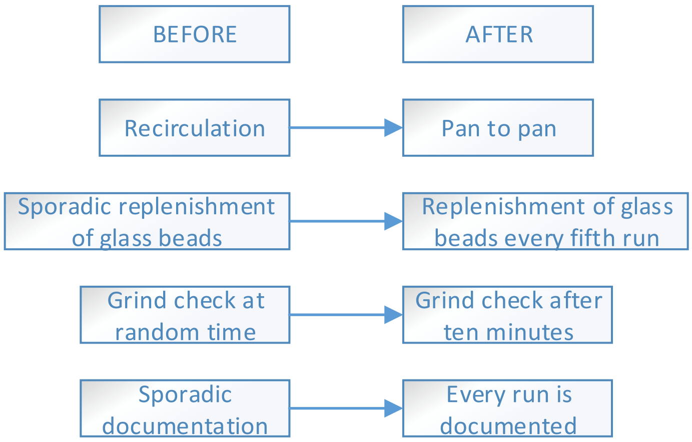

Figure 11 – New working procedure for bead mills eleven and eighteen. The working procedure was developed in collaboration with experienced operators.

After the new standard working procedure had been implemented 15 different products were measured, although only 13 were measured using both methods. A few products were measured more than once. The results confirmed that, for the products that are routed through them, the bead mills are the bottlenecks in the P3 charging department and often make up more than half of the products' lead times. The results further showed that most products only need to run one lap through the bead mill which eliminated the "more work required" argument for recirculation and rather suggested that less work will be required. Unfortunately the two measurement methods for bead mill eleven and eighteen produced results that did not show any signs of a pattern or relationship as illustrated in the tables in Appendix D. The times used when calculating the lead times were all founded on the first measurement method since it had the most measurements. In addition to the 17 products from bead mills eleven and eighteen, five different products were timed on the Cosmo bead mill.

21 products had their unknown dissolver machine times quantified. If several samples were available the shortest sample was used when calculating the lead times. Appendix E contains complete tables of the measured machine times.

4.3. Lead times

The amount of lead times that were completed in AviX was 70, nine more products than the project was first delimited to. These extra products were included due to their similarity to other products that had already been calculated. Based on the product list that was provided by the company there were 57 products for which the lead time was not calculated. Judging from the historical production data from the years 2010 through 2013, which was also supplied by the company, the percentage of produced batches that lead times had been calculated for was 93.4 percent. Of the 70 calculated products, 19 still contain machine times that are unknown but estimable because of similarities with related products. For these products, the actual machine time should not differ by more than plus or minus ten minutes compared to the estimated time although they still need to be investigated at first chance. Four constructed products contain unknown bead mill times that cannot be put in relation to other products' times. These products have been temporarily left out of the scheduling system until their bead mill times have been quantified. Two of these four products are intermediate goods. A number of the calculated lead times are shown in Figure 12. For a complete list of the calculated lead times see Appendix A.

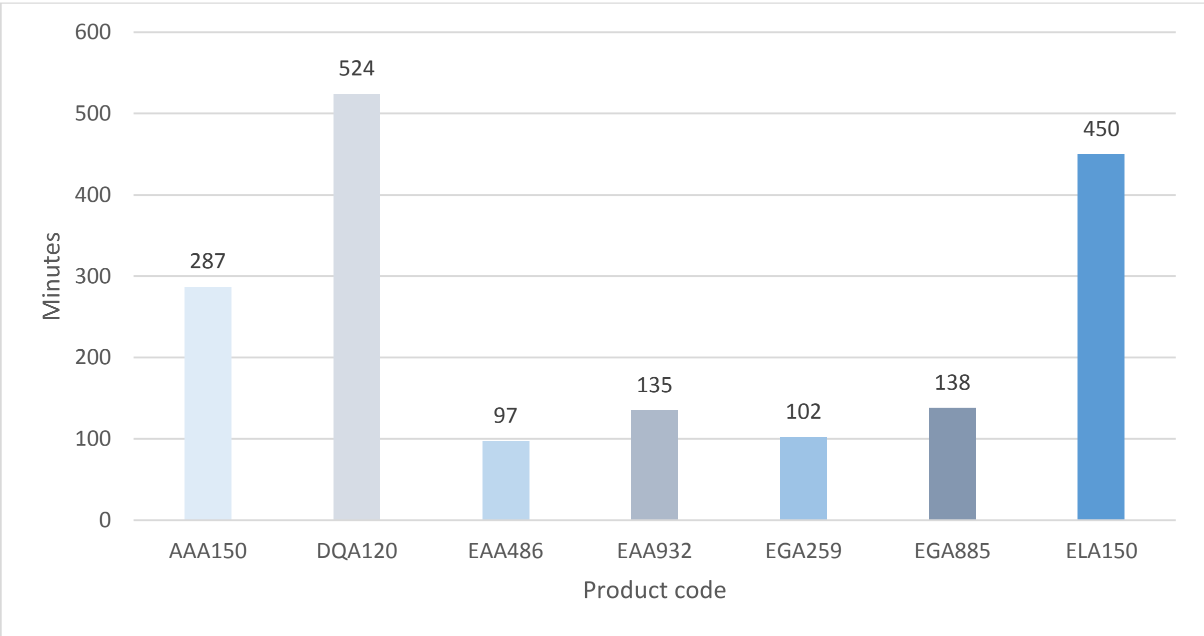

Figure 12 – Some calculated lead times.

The 70 constructed lead times were built up by different combinations of the roughly 800 work tasks that were created in AviX (see Appendix F for one of the work task libraries). Many of these work tasks were in turn built up by many small SAM analyses such as the one presented in Figure 13. The largest routines could contain up to 80 different individual SAM analyses. Out of the roughly 800 work tasks about 700 were at least partially based on several SAM analyses similar to the one in Figure 13. The rest consisted purely of directly measured times. More than half of the work tasks were either walking or forklift transportation tasks.

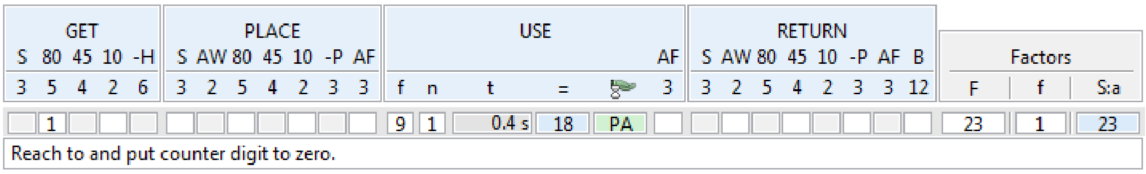

Figure 13 – Example of a SAM analysis.

4.3.1. Overall standards and work procedures

As a result from the data collection and the first live test (see chapter 4.3.2) five important general charging standards were formulated. To follow these standards is quintessential if the operator is to achieve the calculated lead times while still ensuring good quality in the work.

- Always prepare the next charging step on the work order during machine time (if possible), in order to be ready to charge the next raw materials directly after the machine time is up.
- Always keep to the machine times that are specified on the work order.
- Breaks, toilet visits, lunch, telephone calls and other interruptions should be done during machine times if possible. The charging procedure should as a rule not be interrupted.
- Continually tick off all raw materials that have been charged from the work order.
- All adjustments should preferably, if possible, be conducted on a stirrer instead of a dissolver in order to not disrupt the weekly charging plan.

Standards were also formulated for the individual main elements of the charging process, see Appendix C. Many of the work standards were inspired by 5S with regards to minimization of movements and order in the workplace. The idea of converting internal work to external work inspired the standard of always preparing the next step during machine time.

4.3.2. Live test 1 – EGA885

To verify, early on, that the lead times that were constructed in AviX were representative of reality a live test was set up in the beginning of December, 2013. The objective for the operator in the test was to produce one batch of the product EGA885. The operator chosen for the test was thought to work at a rate corresponding to the standard rate. The whole production process was clocked to see if the achieved time would correlate to the calculated time from AviX. The live test was arranged so that the operator would always have access to a forklift and all the necessary tools were to be positioned within reach when needed. Additionally the work procedure and standards that had been constructed in AviX and upon which the calculated lead time was based had to be used, which the operator was made aware of. This work procedure did not differ much from the operator's usual modus operandi. In extension, the test would also show how accurate the calculations of the work tasks were. It was believed that, despite the preparations and arrangements made, disturbances would still occur during the test. Therefore a separate stopwatch was used to clock the time for these disturbances. This stopwatch would be started as soon as the observer (one of the authors of this thesis) noticed a deviation from the intended method of working. When the operator was back on track the stopwatch was stopped but not reset. The final disturbance time would later become the accumulated time of all the small disturbances that were observed during the test. The stopwatch was also used to help the operator keep exact track of the machine times. The results from the test are shown in Figure 14.

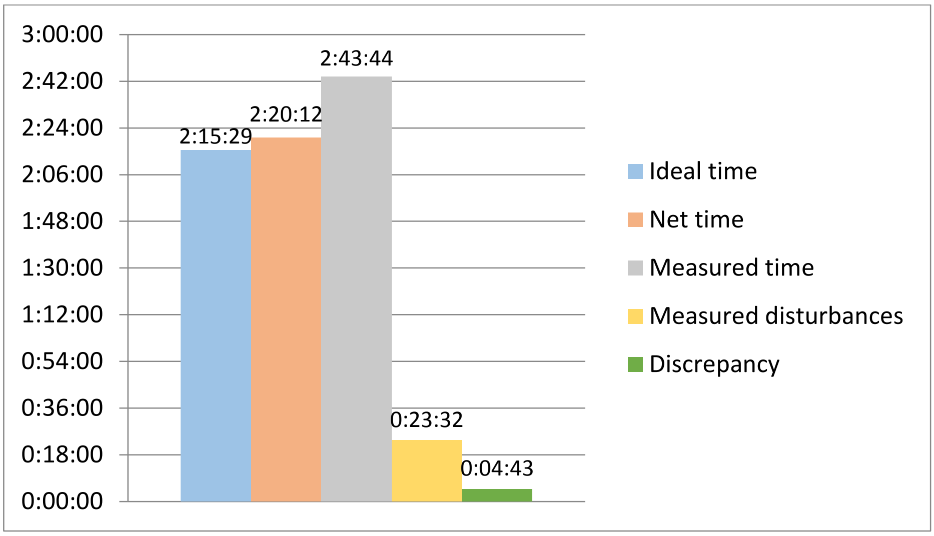

Figure 14 – The results from the first live test with EGA885.

The results show a discrepancy of less than five minutes from the ideal lead time. The ideal time is not easily achieved, being calculated for the standard performance rate and with no margin for error or disturbances. Thus, it was expected that the net time would be slightly larger than the ideal time. The discrepancy was thought to have resulted from small disturbances that were missed by the observer and also from minor deviations from the ideal working method. These results exceeded the expectations and the test was deemed successful. When the test was concluded the operator was asked how it felt to work under the conditions of the test and stated that it did not feel much different compared to usual. This live test also showed that there is a considerable amount of disturbances despite the fact that preparations for the test had been made. The measured disturbances amounted to roughly 14.4 percent of the measured time which corresponds well to the 11 to 15 percent that is usual when calculating allowance time (Allerton (2001)). However, during the test, the operator did not have to tend to any personal needs and showed no signs of fatigue which means all of the measured disturbance time was a result of unforeseen events. This relatively high percentage was expected to be reduced through more thorough work instructions and the introduction of new work standards that at this point of the project had not yet been introduced.

4.4. Scheduling system

The lead times presented as solid-colored bars, see Figure 12, could well be used in a Gantt load chart like the one in Figure 5 but since AviX allows the user to classify work, the bars can be created with more detail, like the bars in a man-machine chart (see Figure 6). This formed the idea to create a load chart scheduling system that combined the Gantt load chart with the man-machine chart. The system was also designed according to FCS but since only a few resources were involved not much computational power would be required. Figure 15 shows the same group of products as shown in Figure 12 but here the product bars have been divided up into their building blocks where the operator work is divided up into direct and indirect and the machine times are divided up between dissolver time and bead mill time. A separate block and color was also used for cooling time but none of the products in Figure 15 required any cooling so it is thus not visible in the figure. Also note that the bars are higher in Figure 15 compared to Figure 12, a result of the fact that the indirect times (yellow band) are present in the latter while not in the former.

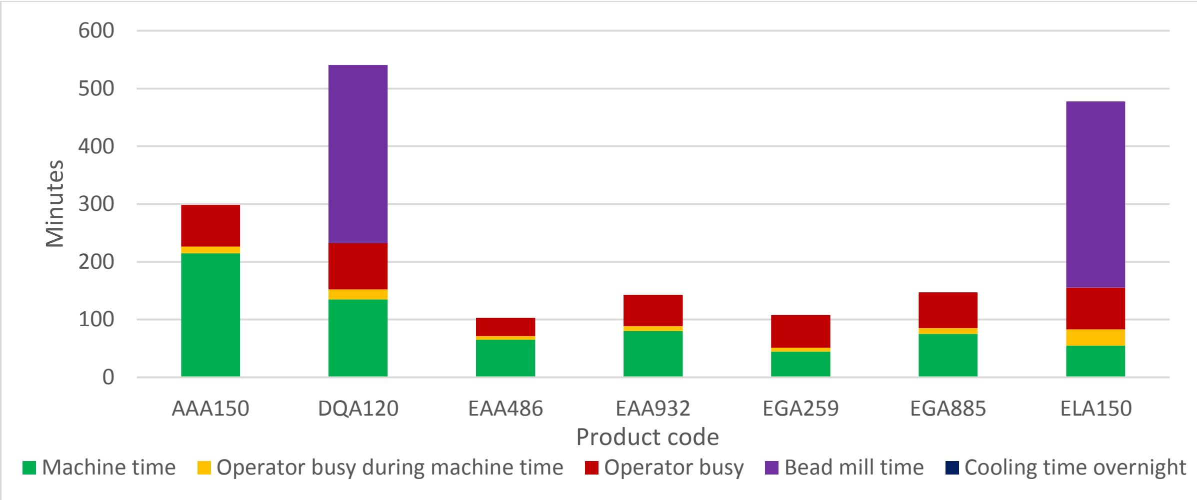

Figure 15 – Some lead times presented as stacked bars including direct and indirect work as well as dissolver time and bead mill time.

If the bars do not exclude indirect times from the total times they will not be representative of the true calculated lead times. To solve this, the indirect times will have to become part of the machine times. However, to just display the amount of direct and indirect work as well as machine times as single blocks would only be marginally helpful to the operators viewing the production plan. Since every product has at least two separate machine times, the operators would, for instance, be unable to tell during which of the machine times a certain amount of indirect work should be performed. To avoid confusion, the lead time bars (from now on referred to as scheduling bars) were designed to graphically represent the work order in a chronological fashion. The scheduling bars for the same group of products as above is shown in Figure 16. The colors are the same as in Figure 15.

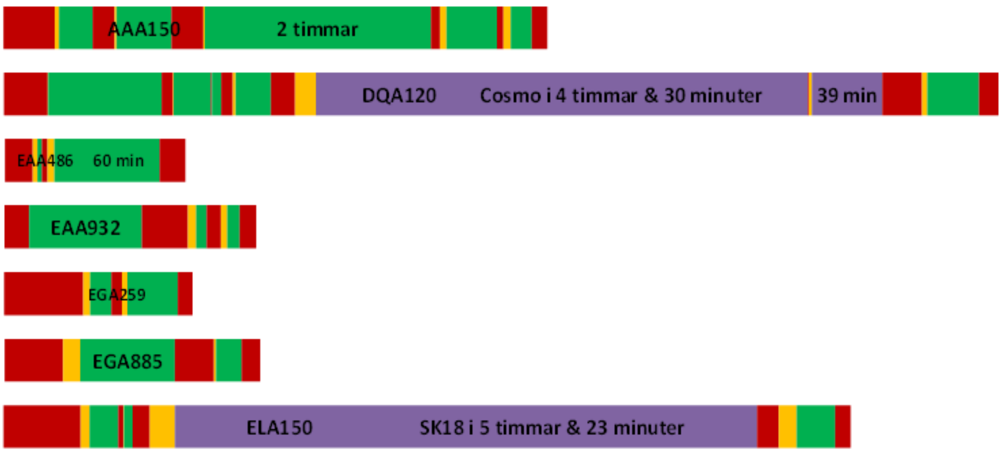

Figure 16 – Scheduling bars.

All the scheduling bars have the same scale so, while there are no gridlines in Figure 16, it is still easy to see that DQA120 has the longest lead time of this group while EAA486 has the shortest, the same as in Figure 15. All scheduling bars will fundamentally have the same structure, only with different amount of machine times and different lengths of the blocks. That means a red block (direct work) is always followed by a yellow block (indirect work) which in turn is followed by either a green (dissolver machine time), purple (bead mill machine time) or dark blue (cooling time) block. Then the pattern repeats itself. The only exception is if there are no indirect tasks required during a specific machine time. In that case red will be directly followed by green, purple or dark blue. DQA120 can be seen to have several examples of this exception. All scheduling bars will begin and end with red blocks. The machine times that are not specified on the work orders have been labeled on the scheduling bars, as well as which bead mill should be used (if any).

The scheduling bars as shown in Figure 16 could be used in the combined Gantt load and man-machine charts to schedule the production of several products in parallel. Since one operator in P3 charging is responsible for two dissolvers and the dissolvers only can handle one product a time two products can be produced in parallel. If also the bead mills are accounted for, one operator could theoretically produce three or four products in parallel.

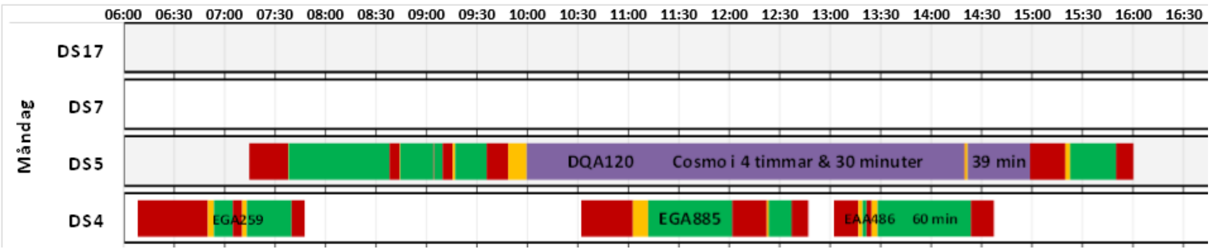

Figure 17 – A snippet from a possible production schedule.

Figure 17 shows a snippet of a possible production schedule for Monday morning up until 16:00 hours for dissolver four and five. The rows for each machine is not wide enough to fit more than one planning bar, which is as it should be because only one product can be produced a time at each machine. At any given moment an operator can only perform one task. A plan like the one in Figure 17 utilizes finite loading, i.e. it is laid out with regards to the machines' and the operator's capacity. This plan is by no means optimal. Dissolver four has an idle period of more than two and a half hours between EGA259 and EGA885. At the same time dissolver five is idle for more than five hours during the time DQA120 has been transferred to the Cosmo bead mill. These idle times are a downside with finite loading (Aswathappa & Shridhara (2010)).

As can be seen in Figure 17 no red or yellow blocks coincide for dissolver four and five. This is a requirement for the operator to be able to follow the schedule, since only one operator should be able to produce the scheduled products at both dissolver four and five. Even if the scheduling bars cover the whole shift, save for roughly the first ten minutes of essential "warm-up" or preparation time, the operator would have plenty of time for recognized breaks if the schedule was followed. This is because the schedule has been fashioned so that machine times coincide with the breaks. To be able to schedule the weekly production in detail like this can greatly increase the production capacity.

4.4.1. Guidelines for scheduling

When creating the production schedule there are three important points to consider:

- No red or yellow blocks should coincide with one another for dissolvers four and five or dissolvers seven and seventeen.

If this is not the case then it would mean that the operator has to work on two products at the same time which is not possible.

- No red or yellow blocks should coincide with any of the operators' recognized breaks.

At around eight o'clock in the morning there should be a twenty minute window for breakfast. At around 10:00 and 13:30 there should be ten minute windows for coffee breaks and between 11:30 and 13:00 a thirty minute window for lunch needs to be allowed. The same goes for the evening shift, except that there is no breakfast break. The idea is to plan for all recognized breaks and to as large extent as possible plan them to coincide with machine times.

- There should be time buffers at the start of the day, end of the day and in between different products scheduled for the same machine.

Since there will always be some preparations required at the start of each day such as donning protective gear, reading the shift report and getting hold of a forklift, the operator cannot be expected to fetch a pan (the defined start of the calculated lead times and therefore also the scheduling bars) at 8:00 sharp. Rather, a five to ten minute "warm-up" time should be scheduled for. When a scheduling bar ends, the operator has just left a quality sample to the lab. If the operator is instantaneously expected to fetch a new pan for the next product the plan will become slightly disrupted. A five minute buffer should be allowed between products. Since disturbances and allowances will always be present, no matter the improvements made, a buffer of at least an hour should be scheduled for at the end of each day. This is to absorb the time that the production lags behind schedule and to ensure that no products will disrupt the schedule for the next day. Using the allowances theory (Allerton (2001)), about 100 minutes should be an adequate buffer at the end of each day.

In addition to these three guidelines, there are several more points that need to be assessed both when creating the schedule and after the schedule has been created:

- Pans should be available of the sorts that are required to be able to produce all scheduled products.

If not, an operator must be assigned to wash the pans that are not already available.

- Raw materials should be available for all scheduled products.

If not, the affected products might have to be moved to later in the week so that raw material deliveries can arrive before the scheduled production start.

- It should be clear who is responsible for printing out the work orders for the respective days.

To ascertain that all work orders are printed out so that all scheduled batches can be pre-batched there must be one operator responsible for this on any given day.

- Operators should be available on both shifts for manning dissolvers four and five as well as dissolvers seven and seventeen.

It is important to know if one of the regular charging operators has scheduled absence for the week in question. If so, there has to be other operators available to fill the role.

- Operators should be available at the pre-batching units so that all batches can be pre-batched prior to the scheduled production start.

In the liquid pre-batching there is one operator working for each shift however in the powder pre-charging there is only one operator, leaving the position unmanned during half of the day. From a scheduling perspective it is important to know which shift the powder pre-batching operator is working on for the week in question.

- Operators should be available on both shifts as replacements for unscheduled operator absence.

If an operator should be absent, another operator must be available to be moved to the charging department and this operator should be notified of this before the start of the week.

- There should be enough time for the filling department to empty pans if it becomes necessary.

Some products have dedicated pans. If several of these products are scheduled for the same week there might be a need to be able to reuse pans. If so, the filling department must be capable of emptying the pans in time.

4.4.2. Digital scheduling system

The scheduling system that was developed for the P3 charging department was built up using Microsoft's Visio software. Microsoft Visio is an application for diagramming and visualization and is a part of the Microsoft Office kit. The digital scheduling system consists of a fixed background image which displays a working week from Monday to Friday and is presented in Figure 19. Friday is shorter than the other four days and ends at 18:30. It was decided that only the dissolvers would have rows on the schedule because all products use the dissolvers while only a few use the bead mills.

A stencil was created in Visio as a library for the scheduling system. The library contains all products, whose lead times were established, that are produced at dissolvers four, five, seven and seventeen. The production planner can drag and drop the products onto the schedule and place them as desired.

Oftentimes, to avoid having red blocks that coincide when two products are run in parallel, the planner may want to make cuts in a scheduling bar. This can easily be done by ungrouping a scheduling bar and selecting which block to move. A theoretical example of a situation that necessitates this is shown in Figure 18.

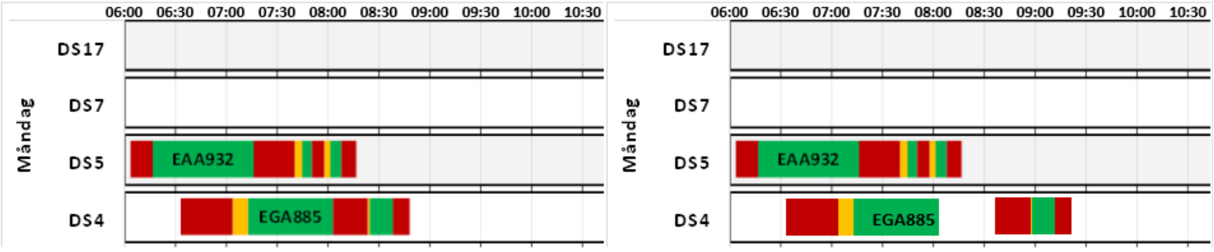

Figure 18 – Example of ungrouping a scheduling bar allowing for more detail.

In the left schedule there are two red blocks that coincide. In the right schedule EGA885 has been ungrouped and split into two parts with the second part moved to after breakfast. The operator would in this case turn off dissolver four during EAA932's last machine time, then finish up EAA932 before going for breakfast. Upon return from the breakfast break the operator proceeds to finish EGA885.

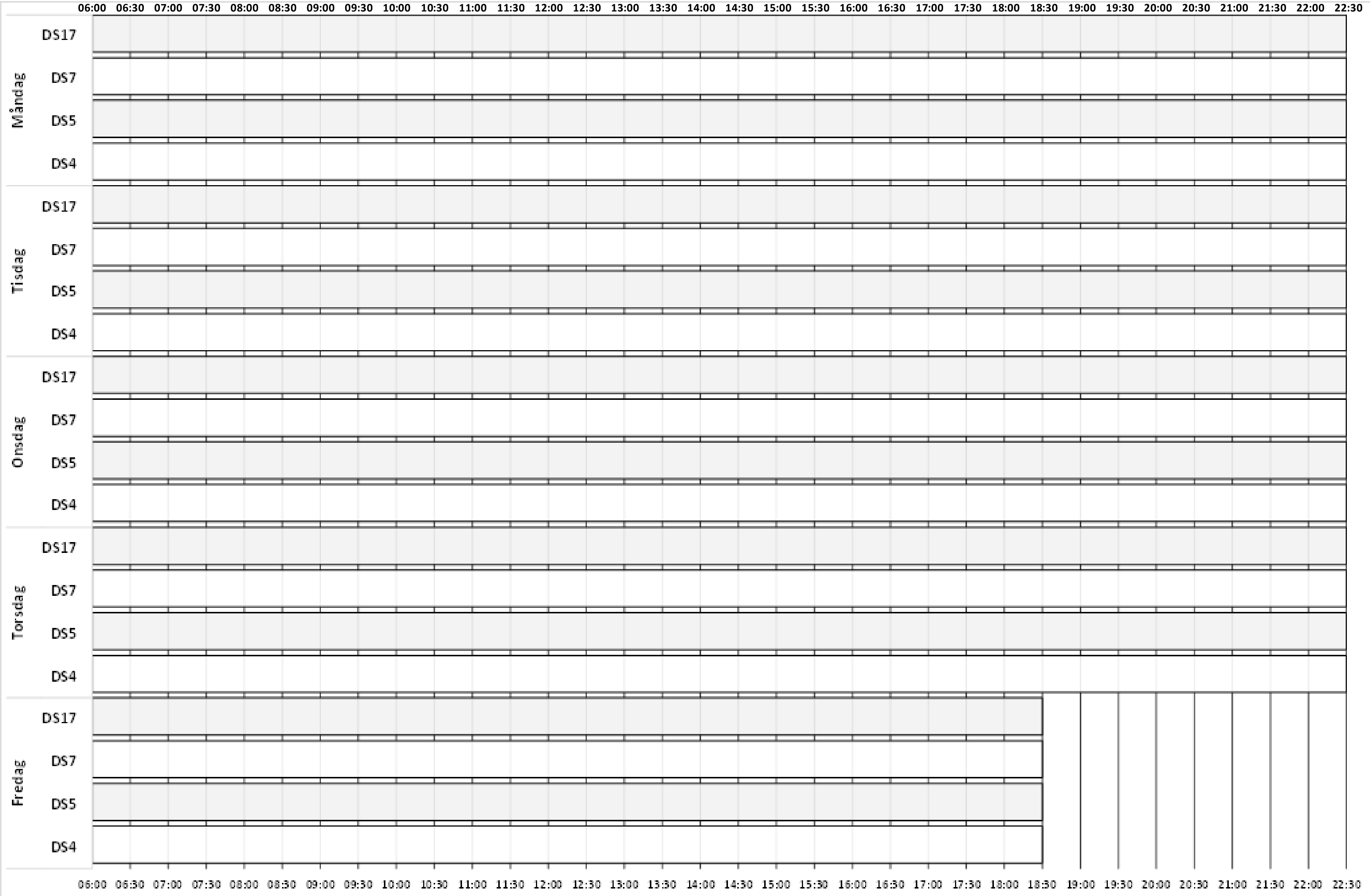

Figure 19 – Schedule layout for one week.

4.5. Live test 2 – Week seven, 2014

A second live test was conducted in order to test the potential of the lead times and the new way of scheduling. A goal was stated that one week of production at dissolvers four and five should be able to be produced in less than two days. All products that were to be produced during week seven can be seen in Figure 20, where each lead time is represented in minutes.

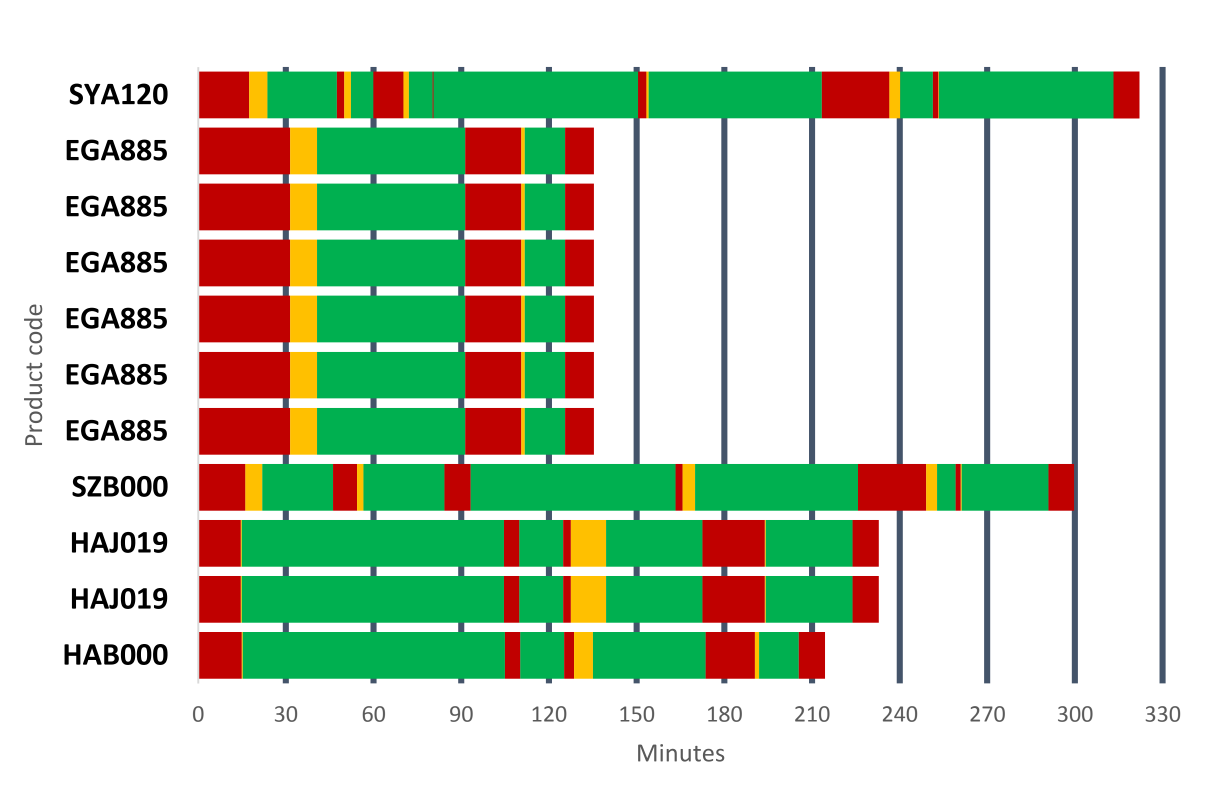

Figure 20 – Scheduled products at dissolvers four and five for the live test week seven.

Like with the first test, prerequisites (see Appendix B) were needed to be arranged and it was also necessary to ensure that the operators were going to work according to the thought-out work standard (Appendix C). The most important new addition to the work standard was that direct work was not to be interrupted. This means the charging operator would for example not answer the phone while performing direct work. Just as in the first test, the operators were assisted in keeping track of the specified machine times with a stopwatch in order to simulate that the operator was in fact used to using a stopwatch when charging.

The weekly schedule was established in cooperation with the concerned charging personnel at P3 and the result can be seen in Figure 21. The charging schedule is distributed over two days with two shifts at each day and one operator charging at each shift at dissolvers four and five. About two hours at the end of each day was left as buffer in case of any unforeseen disturbances.

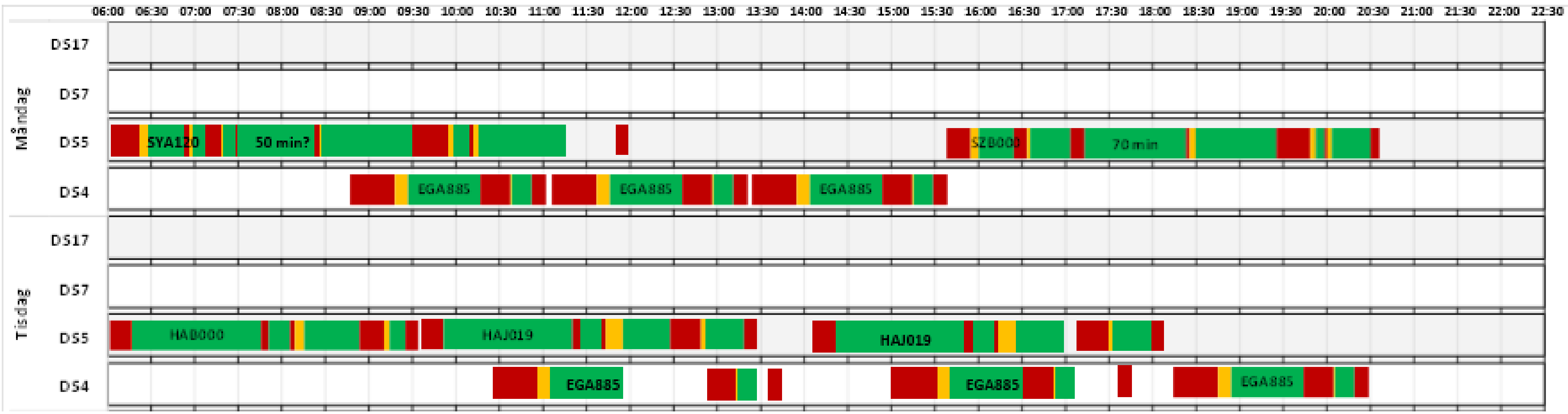

Figure 21 – Charging schedule for the live test week seven, 2014.

Besides checking that the operators were working according to the formulated standards the authors of this report also clocked any measurable disturbances and the accomplished lead times. The results from the live test are presented in Table 5 and 6. Compared to the first live test the disturbances for the second test were generally small. This was seen as a result of a more thorough walkthrough with the operators about the prerequisites for the test as well as the implementation of more standards. None of the operators involved in the test expressed any negative feelings about this new way of working.

Day	Product	Measured lead time [min]	Calculated lead time [min]	Difference [min]
Monday	SYA120	325	322	3
	EGA885	140	136	4
	EGA885	154	136	18
	EGA885	133	136	-3
	SZB000	307	299	8
Tuesday	HAB000	233	215	18
	HAJ019	Not finished	233	Not measured
	HAJ019	Not started	233	Not measured
	EGA885	142	136	6
	EGA885	130	136	-6
	EGA885	223	136	87

Table 5 – Lead time results during the live test week seven.

Day	Summary
Monday	**Measured disturbance:** 54 minutes and 7 seconds **Time behind schedule:** 57 minutes
	Observed disturbances: One extra temperature check, small problems when charging one of the powders, during one instance the operator helped the filling department with checking the level in some tanks.
	Outcome: All planned products produced.
Tuesday	**Observed disturbances:** HAJ019 required a special pan which had not been foreseen before the test which resulted in a delayed startup for the first HAJ019 and the rest of that day's production.
	Outcome: When the dispersion time also was delayed with 1 hour, 7 minutes and 45 seconds for the first HAJ019 and the grind was still not within tolerance it was decided to put it on the Cosmo to grind it. It was then no longer possible to keep the time schedule and the test was aborted.
Total	Nine out of eleven products produced during Monday and Tuesday.

Table 6 – Summary table of the results from the live test during week seven.

4.6. Capacity increase

During week 46 (11/11 to 15/11) 2013 there was in total ten products produced at dissolvers four and five. If all breaks are taken during machine times, the amount of production time available during one week is:

$$990\ minutes * 4 + 690\ minutes = 4650\ minutes$$

Figure 22 visualizes how the charging could have been done if the product lead times had been known during that time, the right prerequisites had been implemented and the thought-out work standard had been followed. Instead of producing these ten products over one whole week it is possible to produce them in less than two days, using the charging schedule in Figure 22. The following calculation showed an increased capacity of 259 percent, where 890 plus 405 minutes is the amount of used production time during Monday and Tuesday. However, a study of the operator absence statistics showed that one of the operators may have been absent the whole week which means the total available production time has to be divided by two, resulting in 2325 minutes, to account for this worst case scenario. The result is still an 80 percent capacity increase.

$$\frac{2325\ minutes}{(890 + 405)\ minutes} \approx 1.80$$

Week seven, visualized in Figure 23, had eleven products which in theory would be able to be charged during less than two days instead of one week. This specific week demonstrated an increased capacity of 166 percent according to the following calculations, where 880 plus 870 minutes are the amount of used production time during Monday and Tuesday:

$$\frac{4650\ minutes}{(880 + 870)\ minutes} \approx 2.66$$

Week nine, visualized in Figure 24, had six products which in theory would be able to be charged during less than two days instead of one week. The capacity could theoretically be increased by 199 percent for this week. One operator may have been absent on one of the days so the total available production time became 3487.5 minutes. 990 plus 565 minutes are the amount of used production time during Monday and Tuesday:

$$\frac{3487.5\ minutes}{(990 + 565)\ minutes} \approx 2.24$$

A summary of the result from the calculated schedules in Figure 22, Figure 23 and Figure 24 is compiled in Table 7. To get a holistic view of the results the average numbers of adjustments made during one week have to be considered, see Table 7. The impact of the adjustments on the results is further discussed in chapter 5.1.

Week	Number of products	Attendance [%]	Needed time present state [min]	Needed time future state [min]	Capacity increase [%]
46	10	50	2325	1295	80
7	11	100	4650	1750	166
9	6	75	3487.5	1555	124
Average	9	75	3487.5	1533.33	123.33
Adjustments made at P3 during 2013					225
Average number of adjustments per week					4.5

Table 7 – Summary of the capacity increase during the three sampled weeks.

The freed up time could be used to continue to produce more batches of the same products as earlier in the week. In this case the potential increased winnings would be equal to the capacity increase, that is, an average of 123.33 percent based on the figures in Table 7.

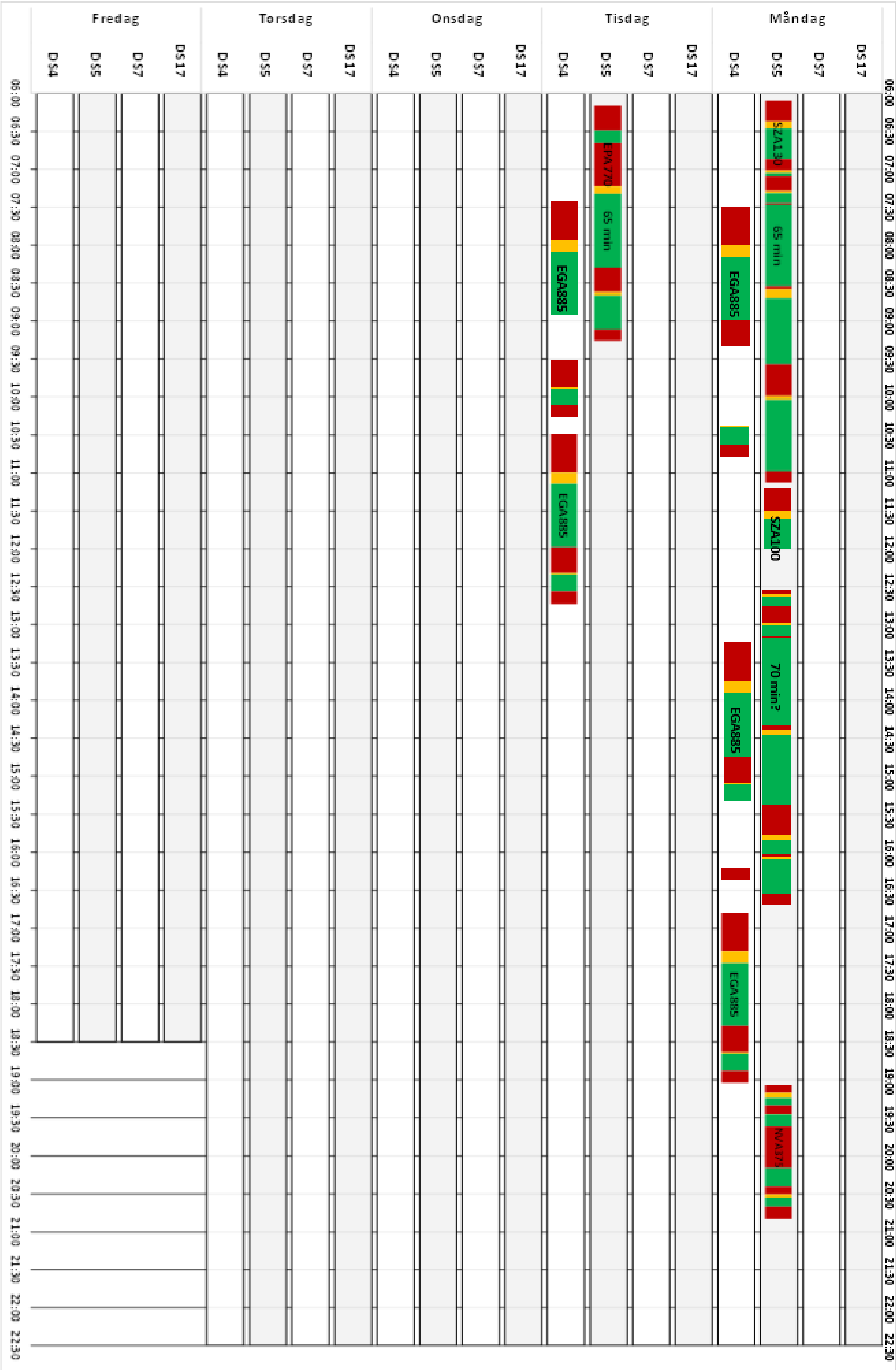

Figure 22 – Improved charging plan for week 46, 2013.

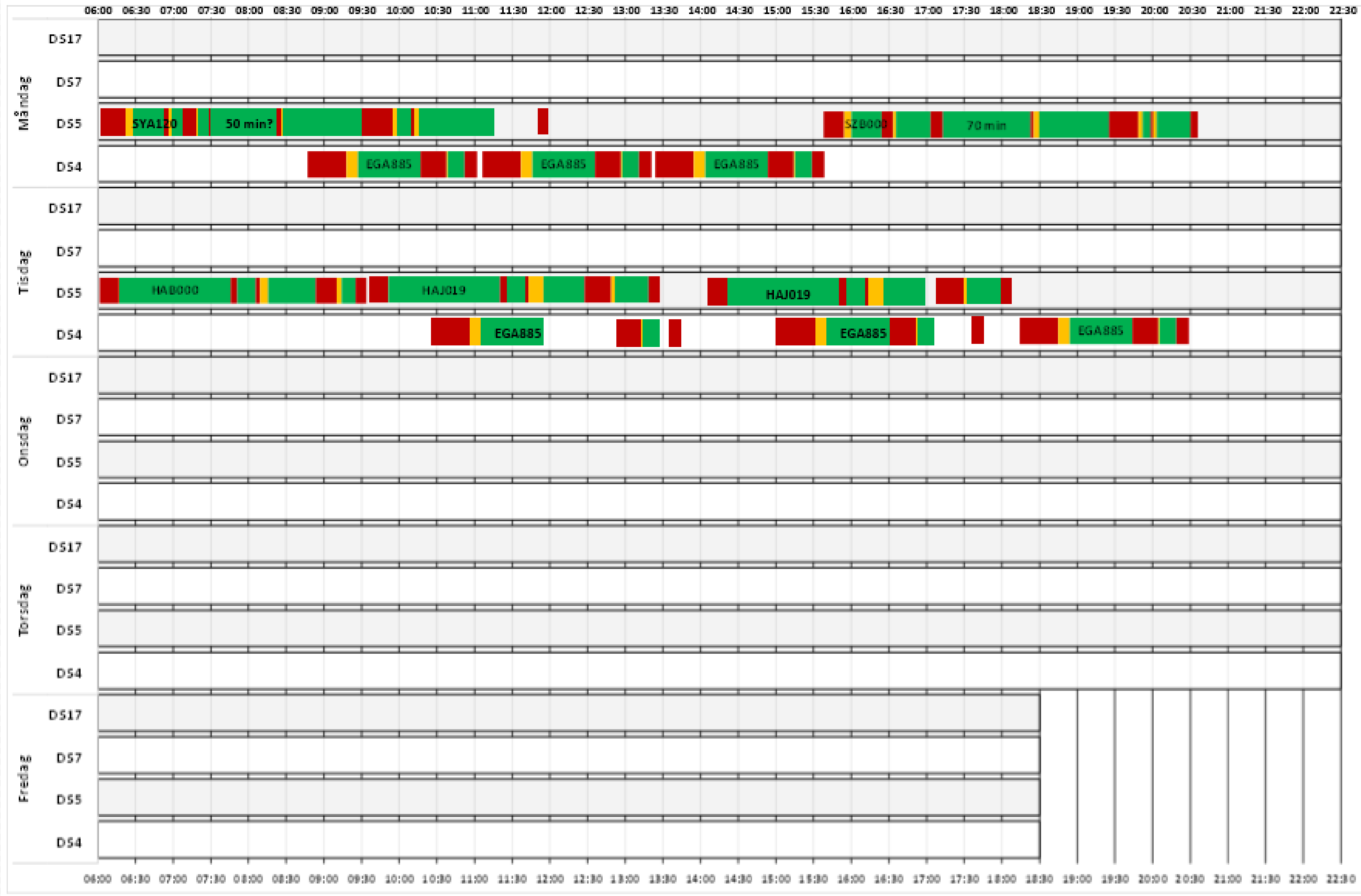

Figure 23 – Improved charging plan for week seven, 2014.

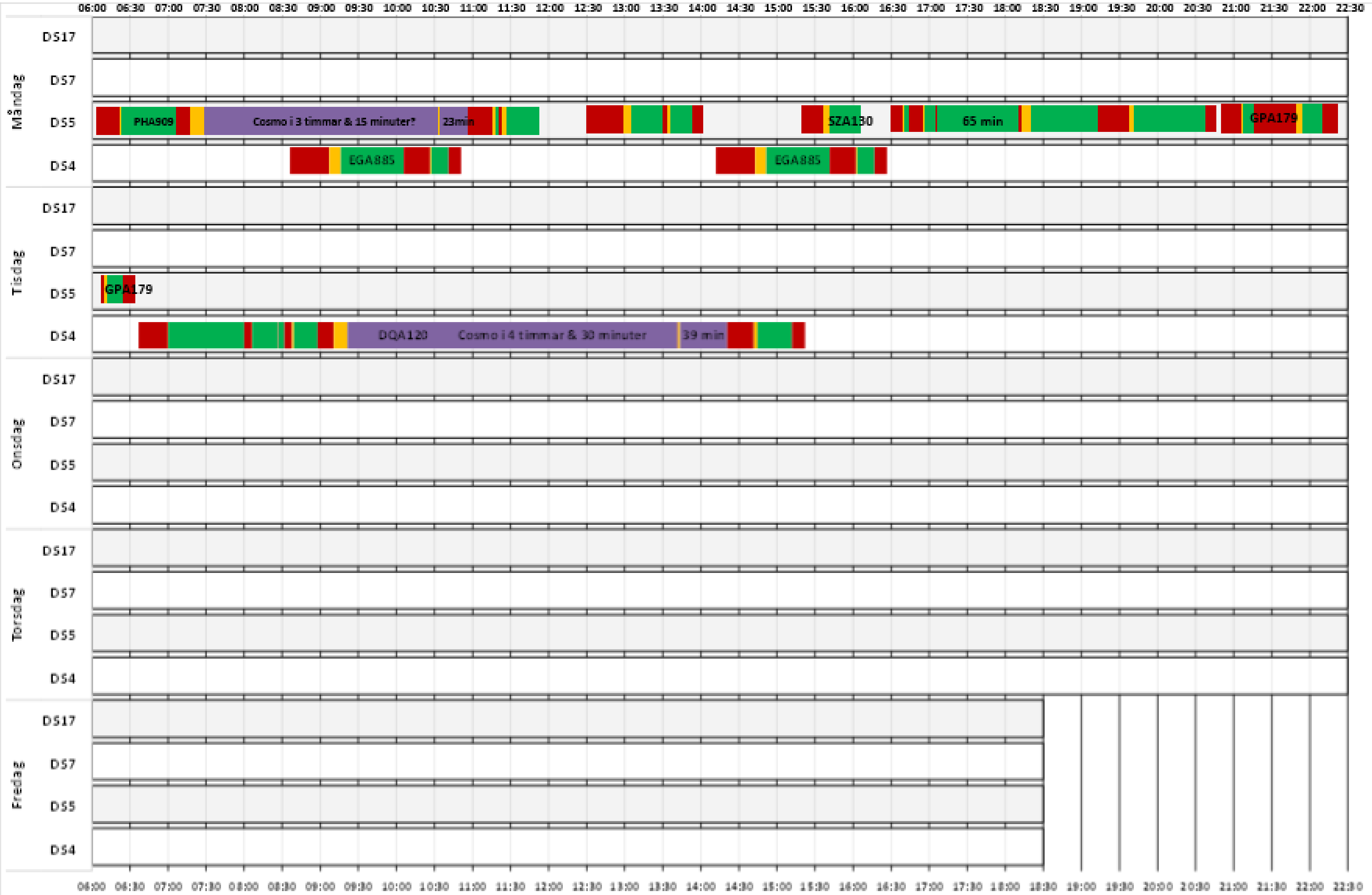

Figure 24 – Improved charging plan for week nine, 2014.

5. Discussion

In this chapter, positive and negative aspects of the utilized methods and the benefits and possibilities of the project results will be discussed. Two next step suggestions for the continuation of this project will be presented as well as some ideas for potential future projects.

5.1. Increased capacity

The results which are presented in Table 7 demonstrate an opportunity for highly increased capacity at the P3 charging department if the right foundation for making a more detailed and accurate weekly charging schedule is available. The main benefit for P3 is that the expected weekly output volume could easily be met, something that has rarely been the case in the past. Whether International decides to use the increased capacity to produce a higher volume of paint is questionable since the current production is based on a demand forecast and over-production is wasteful.

One thing to take into consideration when reading the results in Table 7 is that the amount of time the operators spend on adjusting non-approved batches is not taken into account. This means that besides producing, for example, ten products during week 46 they are also making in average 4.5 adjustments a week, which slightly affects the present capacity. However it is clear by watching the schedules in Figure 22, Figure 23 and Figure 24 that there is time for making adjustment during some of the machine times and it will therefore not affect the overall calculated capacity increase much, if at all, since adjustments can usually be done quickly. Another advantage with this type of scheduling is the detailed overview it gives the operators, which results in a more effective way of handling unexpected work like adjustments. Other than adjustments, the operators will have other tasks that they can attend to when they have time. The most important benefit is that the operators will have plenty of time for charging in dissolvers nine and ten as well as the tanks which represent much of the output volume for P3. 5S is another important task that requires continuous attention in order for the production schedule to completely hold. This includes cleaning, replenishing production tools and equipment and making sure that these are in their designated positions. This is an example of how the scheduling system can contribute to the reduction of disturbances in the production. More time for development and education of the operators will also be available. A further benefit from making detailed schedules is that it frees up more time to make detailed schedules. Finally the saved time created by the increased capacity can be utilized to work with continuous improvements through different improvement projects.

5.2. Live test 2 – Week seven, 2014

The live test conducted during week seven indicates several positive things and supports the reliability of the calculated lead times. Looking at Table 5 it is clear that most of the calculated lead times are close to the measured values collected during the test. The deviations from the calculated lead times can be linked to the overall measured disturbance during Monday presented in Table 5 – Lead time results during the live test week seven.. The measured disturbance was a result from the observed disturbances that was made during the live test. In the end of the first test day the charging plan was delayed with 57 minutes, which is close to the measured delay due to the disturbance of 54 minutes and 7 seconds. The difference between the actual delay and the measured one could be explained by the difficulty of capturing all small disturbances. Two of the measured lead times ended up being shorter than the calculated lead times and these are noted with a negative difference in Table 5. The reason for them being shorter is probably due to decreased amount of set-up time when charging three EGA885 after each other (only the first batch requires set-up) in combination with the fact that there were only minor disturbances during that time.

The second test day was less successful due to first a delay in the startup of the first batch of HAJ019, due to unforeseen pan problems (see Table 5 – Lead time results during the live test week seven.), and then a deviation in the manufacturing process with the same batch. The specified dispersion time for HAJ019 was not enough to reach the tolerance for the grind. This resulted in an elongated dispersion time without any good results, which was why the test was closed down at that point. Due to the prolonged dispersion time the plan was delayed which resulted in switched focus from the last EGA885 to trying to solving the grind problem with HAJ019. This resulted in the last batch of EGA885 having a measured lead time that was 87 minutes longer than the calculated one.

5.3. Method

The overall approach for calculating and constructing lead times described in chapters 3.1 and 3.3.1 has been an advantage since it made it possible to calculate lead times for products that was never observed during the project. Another benefit from this method is that most of the problems (see chapter 2.3.1) occurring when conducting a time study has been avoided, since PTS was mainly used. However in the cases where PTS was not applicable the method of an ordinary time study was applied. The possibility to combine the ordinary time study with PTS has been essential to get complete lead times. The opportunity to reuse the work tasks in several lead times has sped up the lead time construction process and therefore also made it possible to cover the most frequently manufactured products within the projects limited timeframe. None of the authors of this thesis are SAM-certified which may lead to the lead times' reliability being questioned. However it was proven through the live tests (see chapter 4.2.3 and 4.5) that the reliability of the lead times is high.

One approach that might be questioned is the categorization of liquids and powders. This is also an example of how a huge number of different raw materials in combination with limited time forces simplifications. Since the time which these categorizations contribute to the total lead time is relatively small it is correct to assume that possible time deviations between reality and the categorizations have a negligible effect on the accuracy of the calculated lead times.

Another thing that might be questioned is the number of samples used when measuring bead mill times, dispersion times and temperature times. The reason for having such a limited amount of samples here is due to the limited amount of products being produced during this thesis' timeframe. Therefore it is important that the operators continue to measure these times in order to be able to optimize them in an accurate way. Neither of the two measurement methods used for the old bead mills were optimal so preferably a proper mechanical flow meter should be used. For the bead mills, the thought was that some kind of indicator should have been installed on each bead mill pump so that the bead mill settings for a product could be reused each time the same product was running. To install a bead mill pump indicator is an important first step in the implementation phase, as it is not sustainable in the long run to keep measuring the output flow to achieve the right bead mill settings every time. The Cosmo bead mill was measured in a different way compared to the old bead mills. However it remains important to get more samples of the Cosmo times in order to achieve a more accurate and optimized throughput time. The accuracy of the machine time measurements could be disputed, however the measurements from the second live test (see Table 5) indicate that the measured machine times seem to be quite precise, since the real lead times corresponded well to the calculated ones.

Some machine times in the scheduling bars are denoted with a question mark which indicates an uncertainty regarding that machine time because it has not been measured. However these times are qualified estimates, since they are based on those of very similar products that have been measured. This makes it highly unlikely that the difference between the estimated time and the actual time is large.

Since a vital part of the method for calculating lead times relies on the complete understanding of the work orders, the experience gained during three months prior to the start of this project has been irreplaceable. This method would probably have been harder to apply without this experience and the project timeframe would have been too short. Besides just the understanding of the charging process it has also been beneficial to personally know most of the operators, since a good relationship between the operators and the analysts facilitates cooperation and commitment to the project. The operators' general attitude towards the project was always viewed as positive.

5.4. Future state

One interesting point to consider when making improvements to a production process is how the improvements will affect other production processes that have not been dealt with. The charging process at the P3 production department had been determined as the bottleneck of the production process prior to the start of this thesis. Referring to the theory of constraints, there is a chance that once the present bottleneck has been "elevated" a new bottleneck may emerge (Cox & Schleier (2013)). In the P3 department this new bottleneck could be either the filling process or one of the two pre-batching processes. This is something that has to be investigated as the new capacity scheduling becomes fully implemented in the process.

Another question that arises is whether an operator can theoretically charge three products simultaneously on three dissolvers. As shown in Figure 25 this should certainly be possible however it requires a little more thought to the schedule and it has very high sensitivity for disturbances. It also puts demand on the operator to keep track of three machine times simultaneously.

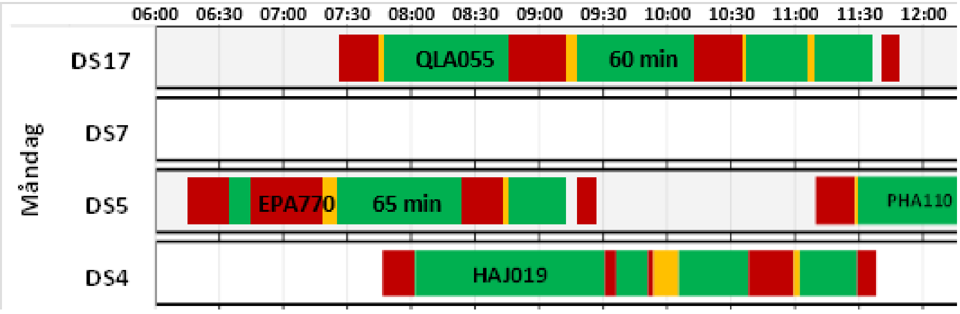

Figure 25 – Example of one operator running three dissolvers at the same time.

This in turn raises the question if more dissolvers can be invested in. A fifth dissolver would increase the production capacity even more. The problem in the present state is that the P3 charging department has no space for a new dissolver.

While the digital production scheduling system that was developed in this thesis is easy to learn and use in addition to the fact that it requires no financial investment for International it is not particularly advanced. Preferably the company can investigate whether there are existing software that can automatically generate the production schedule using certain constraints. This would eliminate the need for the operators to take time off from charging to create the schedule manually.

5.5. Project continuation

It is recommended that International use the results from this project to continuously track changes that are made to the production. Most importantly they need to assign someone, preferably in the role of production technician, to continue building and measuring times. This is also relevant because the product catalogue at P3 is constantly being updated with new products. But not only is it important to update the product lead times. It is equally important to monitor all of the parameters that have an effect on the production. Examples of such parameters could be machine breakdowns, shortages of raw material, deviations in temperature or dispersion times and production disturbances. Through monitoring, International will have a foundation upon which they can base their improvement efforts because attempting to improve a parameter with no potential is wasted time.

The requirements should be that the person appointed to this role needs a SAM-certificate. Furthermore, the company must purchase an AviX license and preferably have the software customized so that the scheduling bars can be automatically generated directly through AviX. This is something that Solme AB has been known to provide. The appointed person must also undergo a learning period to become completely acquainted with the P3 production process and the methodology used by the authors of this thesis.

5.6. Future project suggestions

The authors of this thesis report have during the project's course identified issues related to, but not part of the scope for, this project. They are listed below as suggestions for future projects that International may want to consider.

- Continue calculating the lead times for all the products at P3, including the products produced in the tanks, stirrers and at dissolvers nine and ten. The same can be done at the P1 and P2 charging departments.

- Continue measuring the unknown machine times for the dissolvers and bead mills and when they are known proceed to optimize them. Also investigate whether some specified machine times can be shortened.

- Go through all the work orders for the P3 charging department (and perhaps also for P1 and P2), correct errors on them and create a standard for their layout.

6. Conclusion

This thesis has delivered a new load chart scheduling system based on standardized times to International Paint. This will enable a huge production capacity increase. Moreover, the two research questions that were formulated have been answered.

How can capacity be increased using only available resources?

Over the three sampled weeks an average theoretical capacity increase of 123.33 percent was calculated. This was achieved without investing in any new production equipment or resources. The capacity increase was made possible by introducing a much more accurate way of scheduling the charging for every week. This scheduling system could not have been realized without standardizing the work procedures. The standardized work procedures will help the operators to achieve the calculated lead times, minimize unnecessary movements and also help the operators to deliver the same results time and again, despite which charging operator is performing the tasks.

Furthermore, the scheduling system created in Microsoft Visio facilitates the operators' daily work by visualizing how the time should be spent over a day to achieve the P3 department's weekly charging volume target. It allows the production scheduling to be done easily and quickly. Most importantly it should make the weekly schedules a lot more accurate than in the past.

Is it possible to establish standard times for long-cycle work when there is a big product range?

70 products' lead times have been constructed in AviX, 66 of which now have calculated lead times. All the products include long-cycle manual work. This thesis has shown that the chosen approach can be used to accurately set standard times for long-cycle work, in a limited amount of time, even if the product range is wide.

Setting the standard times would not have been possible without the complete understanding of the production process and the utilization of the predetermined time system SAM. In addition to this, the approach used in this thesis necessitates an extensive and thorough data collection. A huge amount of different measurement data will therefore now be available for International Paint. This data can be used in future projects at the factory and as baselines for continued production monitoring.

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Appendix A – Product lead times

Product	Lead time [min]	Product	Lead time [min]
AAA150	287	**NVA395**	106
DQA120	524	**NVA403**	166[2]
DQA150	823	**NVA405**	103
EAA486	97	**PDA100**	680[2]
EAA932	135	**PDA120**	706[2]
EGA259	102	**PDA130**	234[2]
EGA885	138	**PDB000**	161
ELA150	450	**PDZ999**	931[2]
EMA100	166[2]	**PHA110**	405
EMA120	188[2]	**PHA909**	414
EMA250	417	**PHZ007**	419[2]
EPA110	117	**PMA150**	921
EPA702	135	**QDA049**	103
EPA722	179[2]	**QGA907**	738
EPA730	149	**QLA055**	258
EPA770	187	**QLA703**	726[2]
EPA776	342	**QNP92Y**	681
GPA179	601	**QYA100**	223[2]
HAA720	2069	**QYA130**	216
HAA800	187[2]	**QZA100**	204[2]
HAB000	215	**QZA130**	202[2]
HAD704	233	**QZM785**	214
HAJ019	234	**RSA150**	1337
HTA200	97	**S0497L**	146
HTA453	190[2]	**S0969L**	940
HTA463	183	**SYA120**	304[2]
HTA751	742	**SYA150**	691
JDA120	656	**SZA100**	297[2]
NVA235	189	**SZA120**	296[2]
NVA375	109	**SZA130**	305
NVA376	171[2]	**SZA150**	1033
NVA385	98	**SZB000**	302
NVA392	167[2]	**VTA538**	329
CZA160	Not calculated[3]	**S0964L**	Not calculated[3]
S0957L	Not calculated[3]	**SVA011**	Not calculated[3]

[2] The product lead time still has an unmeasured machine time but due to similarities with related products the unknown machine time can be rather accurately estimated.

[3] The right sequence of work tasks have been created in AviX, however the bead mill time is not measured, which is why the lead time cannot be calculated.

Appendix B – Prerequisites for achieving the calculated lead times

- All formulated standards must be followed by the P3 charging personnel.
- A forklift and manual forklifts must always be available when they are needed.
- All daily used tools (bag knife, ordinary knife, pliers, brush, lid opener, drum wrench, yardstick) should have a designated places on a tool holder located at each dissolver. Some tools like yardstick and ordinary knife should be assigned to every operator to carry in their working overalls.
- Necessary pans should always be available, which puts demands on regular emptying and washing of used pans.
- There should always be a designated spot to put a finished product at. Therefore a pan should always be delivered to the filling department as soon as it is been approved by the quality department.
- All powders and liquids that should be pre-batched are pre-batched and located at their designated pre-batching spot before the charging personnel starts to manufacture a new product.
- All raw materials and manifolds are available when needed during the charging procedure.
- Mugs, sample cans, lid, 5 liter buckets and 20 liter buckets are available at their designated spots when needed. The garbage bin should always be provided with a plastic bag.
- That grind tests are being performed by the charging personnel.
- No interruptions (machine breakdowns, blocked driveways, searching for something, adjustments) occur.
- That temperature checks and grind checks only require one check each during the measured time to confirm the right temperature or grind has been achieved.
- Charging from drums is performed with a forklift at dissolvers four and five. When charging a drum at dissolvers seven and seventeen a drum turner should be used.
- Flux pump is used when charging solvents from the 200 liter pan.
- Charging from container is being performed at the liquid pre-batching area using a scale and a forklift.

Appendix C – Work standard procedures

In addition to the overall standards and work procedure each main charging process has its own standards.

Standard procedure for powder charging

- The mobile garbage bin and powder pallet should be located within arm's length of each side of the charging operator when charging powder at dissolvers four and five. The garbage bin should preferably be placed so the ventilation hose can be connected to it.
- Due to the limited amount of space at dissolvers seven and seventeen, a garbage bag should be used instead of a mobile garbage bin. The garbage bag should be attached to the dissolver and the powder pallet should be located as close to the operator's charging position as possible.
- Make a crescent cut with the knife when opening a powder bag in order to maximize the size of the opening. It is also important to place the bag with its powder filling inlet oriented towards the operator to be able to empty as much powder as possible from the bag.

Standard procedure for liquid charging from bucket

- Place the liquid pallet within arm's length from the charging position when preparing the charging of liquids from buckets.
- Scrape out the remaining liquid from the bucket until it will no longer drip. Not all liquids require scraping (e.g. solvents).

Standard procedure at bead mills eleven and eighteen

- Always use two pans to pump the paint from one pan through the bead mill and out to the other pan. This will assure that all paint runs through the bead mill and is grinded.
- Orient the pans so the pan valves are pointing in the same direction towards the bead mill pump hose so that each pan valve can be reached without switching around the pans.
- The bead mill pump speed should be set at the measured speed in order to achieve an approved grind and the calculated bead mill time. The grind should be checked after ten minutes of starting the mill or adjusting the pumping speed and if the grind is not within tolerances the pumping speed should be adjusted until the grind has been confirmed to be OK.
- When it is time for scraping the pan a manual forklift should be used to tilt the pan as much as possible. Then a scraping tool should be placed in the tilted pan in order to be ready to scrape the paint as soon as the outlet valve is not entirely covered due to the diminishing paint level.
- The bead mill logbook should always be filled in even if it is only an adjustment and not a new product. Glass beads should be refilled for every fifth product or adjustment.

- Bead mill eleven should always be cleaned after every run (if not two batches of the same product are to run through the bead mill directly after each other). The cleaning procedure that is already in place at bead mill eleven should always be followed.

Standard procedure at Cosmo

- Set Cosmo to recirculation until the grind is within tolerances and then pump all the paint through Cosmo into an empty pan.

Standard procedure for charging from manifold

- Check that the manifold is free to use.
- If pumping straight to a dissolver, make sure the pipes are connected from the manifold to the right dissolver.
- For the hardener manifold, check that everything is correctly connected by letting compressed air flow through the system.
- Insert the pig, to be able to clean the pipes after the pumping is completed.
- Start the pumping and check for each pipe connection that nothing is leaking and also check that the fluid is arriving to the right dissolver.
- Perform the pigging procedure when pumping is completed.
- For the hardener manifold, disconnect the pipes to indicate that the manifold is no longer being used.

Appendix D – Raw materials categorization and measurements

Powder categories and measurements

Powder[4]	Category	Dissolver number	Bag size [Kg]	Average time [s]	Average brushing time [s]
PX1	1	4	25	7.66	17.00
PX2	1	4	25	5.82	
PX3	2	4	25	8.95	
PX4	2	4	25	10.58	8.10
PX5	1	4	25	7.73	49.70
PX6	2	5	25	8.64	19.57
PX7	3	4	15	19.85	11.80
PX8	3	4	20	21.06	
PX9	3	4	20	13.10	
PX10	3	4	20		12.00
PX11	3	5	25		
PX12	2	5	25	9.18	19.60
PX13	4	4	25	45.40	21.70
PX14	2	4	25	8.03	16.85
PX15	3	4	25	20.26	8.03
PX16	5	4	10	75.83	15.60
PX17	5	5	25	97.80	30.30
PX18	3	4	22.68		
PX19	3	4	20		
PX20	3	4	22.68		
PX21	3	4	25		
PX22	1	4	25		
PX23	1	4	25		
PX24	3	4	25	18.58	
PX25	1	7	25	5.40	7.50
PX26	2	7	25	10.30	
PX27	1	17	25		
PX28	2	17	25	9.46	19.60
PX29	2	7	25	13.20	23.36
PX30	3	7	20	22.80	
PX31	3	7	20	24.52	22.50
PX32	3	17	25	27.35	13.20
PX33	3	17	9		16.30
PX34	3				
PX35	3		25		

[4] By the request of International, the raw material codes have been replaced with dummy codes.

PX36	4	7	10	42.75	
PX37	4	7	15	43.54	17.34
PX38	4	17	25	29.12	5.05
PX39	4		25		
PX40	5				
PX41	5				
PX42	5	17	10	147.40	33.00
PX43	5	17	25	76.43	3.90
PX44	5	7	20		74.80
PX45	5		10		
PX46		17	2.6		7.80
PX47		17	20		
PX48	2	4	25	10.67	26.13
PX49	2	17	25	9.70	4.98
PX50	1	17	25		
PX51	5	17	10		
PX52	4	17	10	38.80	

Liquid categories and measurements

From bucket			
Liquid[5]	**Category**	**Liquid**	**Category**
LX1	2	**LX21**	2
LX2	2	**LX22**	2
LX3	1	**LX23**	2
LX4	1	**LX24**	2
LX5	1	**LX25**	2
LX6	1	**LX26**	2
LX7	1	**LX27**	2
LX8	1	**LX28**	2
LX9	1	**LX29**	2
LX10	1	**LX30**	1
LX11	1	**LX31**	1
LX12	1	**LX32**	2
LX13	1	**LX33**	2
LX14	1	**LX34**	1
LX15	2	**LX35**	2
LX16	2	**LX36**	1
LX17	2	**LX37**	1
LX18	2	**LX38**	1
LX19	1	**LX39**	1
LX20	2	**LX40**	1

From drum	
Liquid[5]	**Category**
LX1	1
LX2	1
LX3	1
LX4	2
LX5	1
LX6	2
LX7	1
LX8	2
LX9	2
LX10	3

Liquid[5]	**Category**	**From vessel**	**Time [s]**	**Amount [l]**	**Speed [l/s]**
LX1	1	DS4/5 manifold	14.6	40	2.74
LX2	2	Container			1.21
LX3	1	Blue/yellow manifold			2.85
LX4	1	200L pan (flux pump)	20	44.5	2.23
LX5	2	Red manifold			0.51
LX6	2	D9 manifold	71.4	90	1.26
LX7	2	Black manifold			1.24
LX8	2	D9 manifold	11.3	30	2.65
LX9	2	Black manifold			1.28
LX10	2	Hardener manifold	61	100	1.64
LX11	1	DS7/17 manifold	9.4	30	3.19
LX12	1	DS7/17 manifold into 200L pan	7.9	15	1.90
LX13	1	Blue/yellow manifold into bucket	31	17	0.55
LX14	2	Red manifold	59.7	100	1.68
LX15	2	R4 manifold	37.8	100	2.65
LX16	1	LX17 manifold	79.4	20	0.25

[5] By the request of International, the raw material codes have been replaced with dummy codes.

Other measurements

Maximum DS4 blade height above floor [m]	1.455
Minimum DS4 blade height above floor [m]	0.275
DS4 blade height when cleaning [m]	0.9
Distance cleaning height to DS4 minimum height [m]	0.625
Maximum DS5 blade height above floor [m]	1.44
Minimum DS5 blade height above floor [m]	0.25
DS5 blade height when cleaning [m]	0.9
Distance cleaning height to DS5 minimum height [m]	0.65
Time for raising the lid to be able to clean/take a sample [s]	7.5
Time for a blade to stop rotating after turning the engine off [s]	55.1
Avg. time for pouring, checking grind and cleaning all equipment [s]	137.1
Avg. time for cleaning dissolver blade [s]	128.17
Avg. time for drying a dissolver blade [s]	22.1
Avg. time for checking temperature [s]	47
Avg. time for opening a bucket lid with pliers [s]	22.4
Avg. time for installing a pig [s]	2.3
Avg. time for donning one dust protection mask [s]	13.6
Avg. time for removing one dust protection mask [s]	4.6
Time for lowering/raising rotational speed DS4/5 [s/50 rpm]	1.95
Raising/lowering forks on forklift [m/s]	0.21
Fork height when charging DS4/5 [m]	1.575
Time for raising forks to charging position DS4/5 [s]	7.5
Avg. time for scraping blade DS4/5 [s]	115
Avg. time for scraping blade DS7/17 [s]	122
Waiting time for air to come through (time which lever is closed) [s]	4.4
Avg. time for vacuuming dissolver lid [s]	60
Raising/lowering dissolver blade DS7/17 max distance [s]	26.2
Put plastic bag on pan [s]	32.2

Appendix E – Machine times

Bead mill times – First measurement method

Product	Bead mill number	Speed [s/0.5l]	Grind OK?	Temperature [C°]	Total volume [l]	Time for one pan	Laps through bead mill
AJA305	11	9	Y	40	867.8	04:20:20	1
AJA306	11	26	Y	35	886.8	12:48:34	1
AJA404	11	5	Y	32	861.8	02:23:38	3
DQA150	18	16	Y	37	605.9	05:23:09	2
ELA150	18	11	Y	35	878.8	05:22:14	1
ELA150	18	14	Y	35	878.8	06:50:06	1
ELA150	18	18	Y	42	878.8	08:47:17	1
ELA150	18	6	Y	43	878.8	02:55:46	1
EMA250	18	13	Y	45	596.7	04:18:34	1
EMA250	18	18	Y	35	596.7	05:58:01	1
HAA720	11	11	Y		852.2	05:12:28	4
HAA720	11	11	Y	33	852.2	05:00:33	4
MDA402	11	11	Y	45	862.4	05:16:13	1
QNP92Y	11	5	N		738.0	02:03:00	First lap
QNP92Y	11	8	N	35	738.0	03:16:48	Second lap
QNP92Y	11	8	Y	36	738.0	03:16:48	3 Laps required
QNP94X	11	21	Y	39	913.9	10:39:44	1
RSA150	18	9	Y	68	894.4	04:28:19	2
SVA055	18	16	Y		471.4	04:11:25	3
SYA150	18	15	Y	43	671.9	05:35:57	1
SZA150	18	7	Y	45	853.2	03:19:05	1
VTA538	18	19	Y	45	506.7	05:20:55	1
VTA538	18	9	Y	65	506.7	02:32:01	1

Bead mill times – Second measurement method and Cosmo times

Product	Bead mill number	Time [min]	Diameter [dm]	Height [dm]	Volume paint [l]	Speed [l/s]	Total volume [l]	Time for one pan
AJA202	11	21.00	11.85	1.50	165.43	0.1313	845.8	01:47:22
AJA305	11	20.00	12.00	0.50	56.55	0.0471	867.8	05:06:55
AJA306	11	20.00	11.80	0.20	21.87	0.0182	886.8	13:30:55
AJA404	11	22.50	12.60	1.05	130.92	0.0970	861.8	02:28:06
DQA150	18	20.17	11.80	0.30	32.81	0.0271	605.9	06:12:27
ELA150	18	20.00	11.75	0.65	70.48	0.0587	878.8	04:09:22
ELA150	18	20.00	11.75	0.40	43.37	0.0361	878.8	06:45:13
ELA150	18	20.50	11.65	0.35	37.31	0.0303	878.8	08:02:52
ELA150	18	20.33	11.73	1.00	108.07	0.0886	878.8	02:45:21
EMA250	18	20.00	11.45	0.55	56.63	0.0472	596.7	03:30:44
EMA250	18	60.00	11.95	0.75	84.12	0.0234	596.7	07:05:37
HAA720	11	23.83	12.35	0.55	65.88	0.0461	852.2	05:08:14
MDA402	11	67.33	12.15	1.65	191.31	0.0474	862.4	05:03:31
QNP92Y	11	20.25	11.82	0.60	65.84	0.0542	738.0	03:46:59
RSA150	18	20.00	11.85	0.70	77.20	0.0643	894.4	03:51:42
SYA150	18	21.33	11.78	0.70	76.29	0.0596	791.3	03:41:14
SYA150	18	22.67	11.73	0.45	48.63	0.0358	671.9	05:13:14
SZA150	18	35.00	11.30	1.35	135.39	0.0645	853.2	03:40:34

Product	Bead mill	Grind approved	Speed [l/s]	Pumping time to pan
DQA120	Cosmo	4:30:00	0.25	0:38:33
PHA110	Cosmo	3:15:00	0.25	0:18:41
PHA909	Cosmo	2:45:00	0.25	0:23:36
PMA150	Cosmo	3:05:00	0.25	0:25:35
S0969L	Cosmo	12:10:00	0.25	0:57:09

Dispersion times and temperature times

Product	Dissolver number	Time [min]	Grind [µm]
EAA486	4	60	50
EPA770	5	65	50
EPA776	4	193	50
HAA720	7	60	30
HAA720	7	250	30
PDZ999	7	30	50
QYA130	4	80	40
QZM785	5	85	40
S0969L	5	35	Glass plate
THA923	5	30	70

Product	Dissolver No.	Time [min]	Temperature Range [C°]	Measured Temperature [C°]
AAA150	17	120	60-65	60
AJA202	7	55	50	50
AJA202	7	175	60-65	60
AJA304	4	55	50	50
AJA304	4	35	60-65	63
AJA304	5	45	50	50
AJA304	5	72	60-65	60
AJA401	4	55	50	51
AJA401	4	55	60-65	60
AJA403	17	120	50	50
AJA403	17	130	60-65	61
AJA404	7	165	60-65	61
AJA405	5	30	58-60	65
EPA533	4	25	46-50	48
HTA463	4	40	60-65	62
JDA120	5	60	48-50	48
MDA401	4	120	60-65	61
MGA011	5	45	60-65	60
PMA150	17	60	40-43	42
QLA055	17	65	40-43	41
QLA055	17	60	40-43	43
SYA150	7	140	60-62	61
SZA130	4	65	58-60	59
SZA150	17	130	58-60	58
SZB000	4	70	58-60	58
THA923	5	30	50	50

Appendix F – List of work tasks (Library 1)

Task[6]	Time
Remove finished pan to 1000L-pan storage (taking a grind sample & temperature included)	758.7 s
Remove finished pan to 1000L-pan storage (taking a grind sample included)	666.7 s
Remove finished pan to 1000L-pan storage (2.5L quality sample)	554.7 s
Time for cleaning scraping tool	23.0 s
Remove empty pan from pan-to-pan position to washing area	287.6 s
Fetch/place tray on floor	2.9 s
Prepare pan to pan pumping at DS4	94.5 s
Pump pan to pan at DS4 (Preparations NOT included) SPECIFY VOLUME	Variable
Disconnect everything from pump after pan-to-pan pumping and return it to its designated spot	66.8 s
Remove finished pan to 1000L-pan storage (cover the surface with LX1 from hose & plastic bag)	573.6 s
Open/close door	1.6 s
Fetch/place something within reach	0.9 s
Remove plastic protection and rubber band from pan	24.0 s
Fetch/place LX1 within reach	0.9 s
Pour stainer into bucket (Average time)	21.1 s
Take off bucket lid and pour stainer into bucket and reattach lid	76.8 s
Remove finished pan to in front of DS4/5 grind sample included	408.9 s
Return equipment after charging buckets	43.3 s
Remove finished pan to 1000L-pan storage	473.9 s
Fetch/place glass cup when standing by the grind checking area	2.5 s
Remove finished pan to 1000L-pan storage (Vacuuming included)	545.8 s
Start DS7/17 engine	0.4 s

[6] By the request of International, the raw material codes have been replaced with dummy codes.

Charge one powder bag (PX1, 15Kg, DS7)	36.2 s
Fetch plastic bag and mount it next to DS17	0.9 s
Take out plastic bag from storage	0.9 s
Grab handlebar and start driving	2.0 s
Prepare powder charging at DS17	67.7 s
Fix pan under DS4 2nd time	70.4 s
Remove lid off pan at liquid pre-batching and stash it then return to pan (or vice versa)	7.4 s
Place container above pan and ready for charging	9.4 s
Place/fetch tool within reach	0.9 s
Prepare charging of drum with forklift	77.0 s
Reattach bucket lid onto bucket	16.9 s
Open bucket lid with tool	30.5 s
Fetch/place bucket within reach	2.2 s
Place bucket on scale and reset it	2.2 s
Switch to a new drum on the forks	96.5 s
Return everything after charging drum	75.4 s
Time for moving one empty drum from forks to pallet (forklift in position by pallet)	3.9 s
Unscrew drum lever and place it on drum	9.7 s
Screw big drum tap onto drum	2.7 s
Fetch/place drum lever (within reach)	0.9 s
Move 3-step ladder 1m to the left	3.1 s
Screw drum lever onto drum	12.2 s
Unscrew big drum tap and loosen small one with tool	15.1 s
Fetch/place tool	0.9 s
Fetch/place drum lever from/on wash cabinet/something	0.9 s
Raise forks into suitable height for putting drum on it	2.1 s
Time for getting drum on forks	15.3 s
Attach lid locking ring on bucket/loosen lid locking ring and place it on DS1	2.2 s

Place/remove lid on bucket	1.8 s
Preparing flux pumping of solvents at DS4	27.4 s
Take TWO quality samples DS 4	102.2 s
Fetch pig at DS4/5/7/17 pipe-end	0.7 s
Grab handlebar and start driving	2.0 s
Make a note on the recipe	4.9 s
Make a note on the recipe 1 line & 1 sign	4.9 s
Make a note on the recipe 2 lines & 1 sign	6.5 s
Make a note on the recipe 3 lines & 1 sign	7.4 s
Make a note on the recipe 4 lines & 1 sign	8.6 s
Make a note on the recipe 5 lines & 1 sign	9.9 s
Raising/lowering forks to/from ergonomic height	9.3 s
Grab 200L pan handles	0.7 s
Set all levers at hardener manifold (for charging)	11.7 s
Set all levers at hardener manifold (for checking connection with air)	5.6 s
Pigging at D9 manifold	27.6 s
Check if air is coming through the pipe connection	7.3 s
Insert pig in pipe (horizontal pipe)	11.6 s
Set counter hardener manifold (544)	7.0 s
Set counter hardener manifold (221)	4.1 s
Reset counter	2.5 s
Insert pig in pipe DS4/5/7/17	10.2 s
Return garbage bin to its dedicated position/place it in front of DS4	22.6 s
Fix pan under DS4	95.0 s
Clean dissolver blade	127.4 s
Scrape paint off dissolver blade	131.8 s
Dry dissolver blade with paper	22.1 s
Throw garbage into garbage drum	13.3 s

Throw garbage into garbage bin	0.9 s
Fetch paper from paper roll	4.7 s
Fetch powder pallet	66.3 s
Temporarily store or replace (from temporary storage) powder pallet	26.6 s
Get 3-step ladder (DS4)	14.8 s
Raising/lowering forks on forklift	3.7 s
Take a quality sample DS4	66.7 s
Fetch dust protection (from cabinet) and don it	25.5 s
Don dust protection	13.6 s
Remove dust protection	4.6 s
Take a grind sample, check the grind (DS4) & return to cabinet	182.8 s
Take a GLASS PLATE grind sample, check the grind (DS4) & return to cabinet	151.4 s
Prepare for taking a grind sample DS4/5/7/17	1.8 s
Check paint level in pan DS4	15.5 s
Leave scraper	5.4 s
Fetch scraper	28.4 s
Charge ullage DS4/5	158.9 s
Charge ullage DS7	164.5 s
Charge ullage DS17	162.9 s
Stop/start dissolver engine	1.1 s
Walk from/to grind test area bin to/from 1-step ladder by DS17	3.8 s
Place bucket on DS7/17/pallet	0.9 s
Stop/start hydraulic motor	1.1 s
Raise/lower dissolver lid DS4/5/7/17	1.3 s
Check temperature	92.0 s
Return thermometer	0.9 s
Remove pig DS4/5/7/17	15.3 s
Attach kanban card to pan DS4	11.9 s

Elevator time (includes pushing the button)	27.7 s
Raise manual forklift for fetching pallet/pan etc.	7.6 s
Insert manual forklift under pan/pallet	2.2 s
Close/open elevator doors	1.8 s
Grab manual forklift/electrical forklift	1.8 s
Put plastic bag on pan (includes opening the bag)	32.2 s
Connect pipes	10.3 s
Attach stripes to secure pipe locking mechanism	19.6 s
Fetch/place bucket/2 buckets on floor	2.2 s
Vacuum dissolver lid DS4/5	65.9 s
Remove finished pan to in front of DS4/5	226.6 s
Remove finished pan to 1000L-pan storage (Insert nitrogen gas & plastic bag)	515.5 s
Return L-pipe and extension from D9 manifold	35.3 s
Take a 2.5L quality sample DS4	148.5 s
Charging from DS4/5 manifold	24.4 s
Charging from DS4/5 manifold 2nd time	24.9 s
Charge LX1 into DS4 pan when fixed under dissolver & return LX1 hose SPECIFY UNIQUE VOLUME	Variable
Charge from red manifold then 3 solvents from blue manifold SPECIFY UNIQUE VOLUME	Variable
Charge 2 from red manifold then 3 solvents from blue manifold SPECIFY UNIQUE VOLUME	Variable
Charge 2 solvents from blue manifold SPECIFY UNIQUE VOLUME	Variable
Charge from 20L bucket (scraping included) LESS THAN 7KG	63.7 s
Charge from 20L bucket (scraping included) MORE THAN 7KG	67.9 s
Charge from red manifold then 2 solvents from blue manifold and 1 solvent from yellow manifold SPECIFY UNIQUE VOLUME	Variable
Pour one bucket (independent of amount of stainer in bucket) of stainer into the dissolver, scraping time included	67.0 s
Charge from red manifold then 1 solvents from blue manifold README!!! SPECIFY UNIQUE VOLUME	Variable
Pour LX1 into pan	2.6 s
Prepare charging from bucket	52.2 s
Pour stainer (S0958L 0.2 + S0964L 4.1 + S0957L 12.1) into dissolver (scraping time included)	67.0 s

Take off bucket lid and pour stainer (S0957L, 12.1Kg) into bucket and reattach lid	77.9 s
Take off bucket lid and pour stainer (S0958L, 0.2Kg) into bucket and reattach lid	77.5 s
Take off bucket lid and pour stainer (S0964L, 4.1Kg) into bucket and reattach lid	75.0 s
Pour stainer into bucket (S0957L, 12.1Kg)	22.2 s
Pour stainer into bucket (S0958L, 0.2Kg)	21.8 s
Pour stainer into bucket (S0964L, 4.1Kg)	19.3 s
Charge from drum (LX1, 106 Kg, DS4)	100.9 s
LX1, 106Kg emptying time	76.0 s
Charge from drum (LX1, DS4)	155.5 s
LX1 emptying time	130.6 s
Weigh up cat. 2 liquid at liquid pre-batching SPECIFY UNIQUE WEIGHT	Variable
Flux pumping of solvents at DS4 when already prepared	66.1 s
Flux pumping of solvents at DS4 when already prepared 2nd time	61.1 s
Charge from blue manifold into 2 buckets, 27L 2 buckets with 13 in one and 14 in the other	142.5 s
Charge two solvents from blue manifold into 200L pan SPECIFY UNIQUE VOLUMES	Variable
Charge LX1 to DS4 from hardener manifold 221L	370.6 s
Charge from blue manifold into 200L pan SPECIFY UNIQUE VOLUME	Variable
Flux pumping solvents at DS4 SPECIFY UNIQUE VOLUME	Variable
Flux pumping 2 solvents at DS4 SPECIFY UNIQUE VOLUME	Variable
Charge LX1 to DS4 from hardener manifold 544L	901.6 s
Charge from blue manifold SPECIFY UNIQUE VOLUME	Variable
Charge from red manifold SPECIFY UNIQUE VOLUME	Variable
Charge LX1 in pan after pumping pan-to-pan (scraping included) SPECIFY VOLUME	Variable
Charge from blue manifold into bucket (SPECIFY VOLUME)	Variable
Charge from yellow manifold into bucket (SPECIFY VOLUME)	Variable
Charge from 20L bucket (Solvent, DS4)	23.2 s
Charge from 5L bucket (LX1, 0.4 KG, DS4)	20.6 s
Charge from 20L bucket (LX1, 1.4 KG, DS4)	20.6 s

Charge from red manifold then 2 solvents from blue manifold SPECIFY UNIQUE VOLUME	Variable
Charge one powder bag (PX1, 25Kg)	18.5 s
Final cleaning of grating after charging aluminum paste	30.3 s
Brush powder into dissolver PX1 cat. 1 (should be used for powders which only require one brushing time)	20.2 s
Brush powder into dissolver PX2 cat. 1 (should be used for powders which only require one brushing time)	25.7 s
Charge one powder bag (Small amount Less than 40% of weight or volume)	24.2 s
Charge one powder bag (PX1, 25 Kg, DS4)	46.1 s
Charge one powder bag (PX2, 25 Kg, DS4)	34.5 s
Charge one powder bag (PX3, 15/25 Kg)	76.8 s
Charge one powder bag (PX4, 25 Kg, DS4)	20.3 s
Charge one powder bag (PX5, 25 Kg, DS4)	50.8 s
Charge one powder bag (PX6, 5 Kg, DS4)	43.7 s
Charge one powder bag (PX7, 20Kg, DS4/5/7/17)	37.2 s
Charge one powder bag (PX8, 15 Kg)	44.2 s
Charge one powder bag (PX9, 18.8 Kg)	47.5 s
Charge one powder bag (PX10, 5 Kg)	30.7 s
Charge one powder bag (PX11, 25 Kg, DS5)	44.6 s
Charge aluminum paste from 25 Kg bucket	122.2 s
Charge one powder bag (PX12, 14 Kg, DS4)	17.0 s
Charge one powder bag (PX13, 12 Kg, DS5)	39.6 s
Brush powder into dissolver PX3 cat. 1 (should be used for powders which only require one brushing time)	20.2 s
Charge one powder bag (PX14, 15Kg)	47.5 s
Charge one powder bag (PX15, 10.8Kg)	41.9 s
Brush powder into dissolver PX4 cat. 1 (should be used for powders which only require on brushing time)	10.7 s
Charge one powder bag (PX16, 25 Kg, DS5)	44.1 s
Charge one powder bag (PX17, 25Kg, DS 4/5/7/17)	20.3 s
Charge one powder bag without brushing (PX18 25Kg, DS4)	18.0 s
Charge one powder bag (PX19, 2 Kg, DS4)	43.6 s

Charge one powder bag (PX20, 10 Kg, DS4)	107.3 s
Charge one powder bag (PX21, 10 Kg, DS4) Empty time = PX19	104.3 s
Charge one powder bag (PX22, 20 Kg, DS4)	49.5 s
Charge one powder bag (PX23, 20 Kg, DS7)	51.2 s
Charge one powder bag (PX24, 25 Kg)	52.4 s
Machine time 20 min	1,200.0 s
Machine time 80 minutes	4,800.0 s
Wait for the paint to cool until next day (8 hours)	28,800.0 s
Machine time 5 minutes ONLY TIME	300.0 s
Machine time 70 minutes ONLY TIME	4,200.0 s
Increase/decrease DS4 rotational speed 300rpm	13.1 s
Raise/lower dissolver blade to maximum height	16.4 s
Machine time 30 min ONLY TIME	1,800.0 s
Machine time 45 min ONLY TIME	2,700.0 s
Machine time 1h 30 min ONLY TIME	5,400.0 s
Increase/decrease DS4 rotational speed 450rpm	19.1 s
Machine time 60 minutes ONLY TIME	3,600.0 s
Increase/decrease DS4 rotational speed 150rpm	7.1 s
Machine time 10 minutes ONLY TIME	600.0 s
Machine time 15 minutes ONLY TIME	900.0 s
Increase/decrease DS4 rotational speed 250rpm	11.1 s
Raise/lower dissolver blade DS4 (for cleaning blade or taking sample)	9.4 s
Raise/lower dissolver blade DS5 (for cleaning blade or taking sample)	9.7 s
Raise/lower dissolver blade from sample height to maximum height	8.6 s
Time for blade to accelerate to ~350rpm DS4	3.0 s
Time for blade to stop from ~350rpm	55.0 s
Walk from/to forklift between P1 and P3 to/from DS4/5 control panel	19.4 s
Walk from/to pan by D9 manifold to/from DS4/5 control panel	16.7 s

Walk from/to pan by D9 manifold to/from forklift between P1 and P3	4.3 s
Walk from/to DS1 to/from 3-step ladder designated spot	5.9 s
Walk from/to DS1 to/from S0056L weighing spot at P2	23.8 s
Walk up/down to/from elevator from/to elevator	41.6 s
Walk from/to LX1 hose designated spot to/from forklift (in front of DS4)	5.9 s
Walk from/to LX1 hose designated spot to/from 3-step ladder (in front of DS4)	5.9 s
Walk from/to blue cabinet to/from LX1 hose designated spot	6.5 s
Walk with empty 600L-pan from/to pan (in pan-to-pan position) to/from outside elevator P1 side	15.7 s
Walk from/to DS4 control panel to/from LX1 valve lever	6.5 s
Walk from/to outside elevator to/from elevator doors	2.2 s
Walk with pan into elevator from outside elevator	4.3 s
Walk from/to elevator lower P2 side to/from blue cabinet	34.6 s
Walk out from elevator	1.1 s
Walk from/to DS4 control panel to/from liquid pre-batching area	49.1 s
Walk from/to pumping spot by DS4 to/from forklift	4.3 s
Walk from/to mobile pump designated spot to/from pan to pan pumping spot	7.0 s
Walk from/to DS4 control panel to/from pumping spot by DS4	3.8 s
Walk from/to pan (in pan-to-pan position) to/from blue cabinet	3.2 s
Walk from/to LX1 hose designated spot to/from DS4 control panel	7.0 s
Walk from/to DS1 to/from scraping tool at P2 side	9.2 s
Walk from/to scraping tool at P2 side to/from pan (in pan-to-pan position at P1 side)	10.8 s
Walk from/to mobile pump designated spot to/from pan (in pan-to-pan position)	7.0 s
Walk from/to LX1 hose designated spot to/from DS4 left side	5.9 s
Walk from/to left side DS4 to/from LX1 valve lever	5.4 s
Walk from/to LX1 hose designated spot to/from garbage bin	9.2 s
Walk from/to blue cabinet to/from nearest paper roll	4.9 s
Walk from/to 3-step ladder (in front of DS4) to/from LX1 valve lever	3.2 s
Walk from/to 3-step ladder (in front of DS4) to/from LX1 filling point	5.9 s

Walk from/to LX1 valve lever to/from blue cabinet	2.2 s
Walk from/to S0957L to/from S0946L in stainer room	4.3 s
Walk from/to S0946L to/from scale in stainer room	4.9 s
Walk from/to DS1 to/from LX1 valve lever	3.2 s
Walk from/to blue cabinet to/from LX1 filling point (behind DS5)	6.5 s
Walk from/to DS1 to/from LX1 filling point (behind DS5)/3-step ladder designated spot	6.5 s
Walk from/to LX1 valve lever to/from LX1 filling point	7.6 s
Walk from/to blue cabinet to/from 200L-pan designated spot	4.3 s
Walk from/to DS1 to/from 200L-pan designated spot	3.2 s
Walk from/to blue cabinet to/from grind room	9.9 s
Walk from/to grind room to/from LX1 room	80.3 s
Walk from LX1 room to blue cabinet	92.3 s
Walk from/to S0957L-place to/from S0964L	3.2 s
Walk from/to nearest paper roll to/from 3-step ladder	3.2 s
Walk from/to DS1 to/from forklift in front of DS4/5	2.7 s
Walk from/to blue cabinet to/from flux pumping spot DS4/5	2.7 s
Walk from/to DS4 locking point to/from forklift in front of DS4/5	5.9 s
Walk from/to DS4/5 control panel to/from wash pan dedicated place	4.9 s
Walk from/to sink to/from 3-step ladder in front of DS4/5	6.5 s
Walk from/to forklift in in front of DS4/5 to/from wash pan dedicated spot	4.9 s
Walk from/to pan under dissolver to/from DS4/5 control panel	2.7 s
Walk from/to forklift in liquid pre-batching to/from next to container	2.2 s
Walk from/to next to container to/from pan in liquid pre-batching	1.6 s
Walk from DS4 pipe-end to forklift (in front of DS4)	4.9 s
Walk from 3-step ladder designated spot to DS4 right side (pan locking point)	8.1 s
Walk from/to DS4 right side to/from DS4 pipe-end	3.8 s
Walk from/to DS4/5 control panel to/from DS1	4.9 s
Walk from/to scale in stainer room to/from DS4/5 control panel	28.1 s

Walk from/to S0958L to/from S0964L in stainer room	3.2 s
Walk from/to S0964L to/from scale in stainer room	3.2 s
Walk from/to S0958L to/from scale in stainer room	2.7 s
Walk from/to S0957L to/from S0958L in stainer room	2.2 s
Walk from/to scale in stainer room to/from S0957L-place	4.9 s
Walk from/to DS1 to/from stainer room	23.2 s
Walk from forklift to drum on forks	2.2 s
Walk from/to forklift (in drum charging position) to/from 3-step ladder beside dissolver	1.1 s
Walk from/to forklift to/from drum (when forklift is beside pallet with drum on)	2.7 s
Walk from/to blue cabinet to/from forklift (in front of DS4/5)	4.3 s
Walk from/to garbage bin to/from forklift (in front of DS4/5)	1.6 s
Walk from/to garbage bin to/from DS1	3.8 s
Walk from/to sink to/from DS4/5 control panel	9.7 s
Walk from/to forklift (in front of DS4/5) to/from laboratory	28.8 s
Walk from/to sink to/from DS4/5 control panel	9.7 s
Walk from/to forklift (in front of DS4/5) to/from laboratory	28.8 s
Walk from/to forklift (in front of DS4/5) to/from DS4/5 control panel	5.9 s
Walk from/to DS1 to/from B/Y manifold	18.4 s
Walk from garbage bin dedicated spot to DS4 pipe-end (left side)	6.5 s
Walk from DS4/5 control panel to DS4 pipe-end (left side)	1.6 s
Walk from flux pumping spot to DS4/5 control panel	3.8 s
Walk from DS4/5 control panel to 3-step ladder designated spot	5.9 s
Walk from forklift (in front of DS4/5) to/from 200L-pan designated spot	2.7 s
Walk from/to 3-step ladder (in front of DS4/5) to/from 200L pan designated spot	4.3 s
Walk from/to DS4 flux pumping spot to/from M1-pipe	12.4 s
Walk from/to hardener manifold to/from DS4/5 control panel	17.3 s
Walk from/to DS4 right side to/from DS4/5 flux pumping spot	4.3 s
Walk from/to DS1 to/from blue cabinet	2.2 s

Walk out from elevator	1.1 s
Walk from/to 3-step ladder (in front of DS4) to/from DS1	1.6 s
Walk from/to 200L-pan designated spot to/from M1-pipe	8.6 s
Walk from/to DS4 right side to/from 200L-pan designated spot	6.5 s
Walk from/to DS4 right side to/from 3-step ladder (in front of DS4)	2.7 s
Walk from/to 200L-pan designated spot to/from DS4/5 flux pumping spot	5.4 s
Return 200L pan to designated spot	8.1 s
Walk from/to B/Y manifold with 200L pan to/from DS4/5 flux pumping spot	44.8 s
Walk with 200L pan from its designated spot to B/Y manifold	41.6 s
Walk to 200L pan designated spot from DS4/5 control panel	6.5 s
Walk around 200L pan to DS4 pipe-end	2.2 s
Walk to/from pressurized air source pipe next to blue cabinet	3.2 s
Walk from/to hardener manifold to/from DS4 right side (pipe-end point)	21.6 s
Walk from hardener pigging position to hardener counter	1.1 s
Walk from/to garbage bin to/from temporary powder storage	2.7 s
Walk from/to forklift in front of DS4 to/from M1-pipe	10.8 s
Walk from/to forklift outside P2 to/from B/Y manifold	3.8 s
Walk from/to 3-step ladder designated spot to/from forklift (in front of DS4/5)	4.9 s
Walk from/to 3-step ladder to/from forklift (in front of DS4/5)	3.2 s
Walk from/to temporary powder storage to/from 3-step ladder (in front of DS4)	2.7 s
Walk from/to blue cabinet to/from DS4/5 control panel	4.9 s
Walk from/to blue cabinet to/from 3-step ladder (in front of DS4)	1.1 s
Walk from/to blue cabinet to/from 3-step ladder(in front of DS5)	2.7 s
Walk from/to right side of DS4 (pan locking point) to/from DS4 control panel	5.9 s
Walk to DS4 level measuring point from DS4/5 control panel	1.6 s
Walk from DS4 level measuring point to blue cabinet	3.2 s
Walk from/to DS4 sampling point to/from blue cabinet	3.2 s
Walk from/to DS4/5 control panel to/from nearest paper roll	6.5 s

Walk from/to paper roll to/from 3-step ladder (in front of DS4)	3.2 s
Walk from/to paper roll to/from 3-step ladder (in front of DS5)	4.3 s
Walk from/to nearest paper roll to/from DS4 pan	4.9 s
Walk from/to nearest paper roll to/from DS5 pan	5.4 s
Walk from/to DS4-pan to/from garbage drum	8.6 s
Walk from/to DS5-pan to/from garbage drum	8.6 s
Walk from/to sink to/from laboratory & place sample on shelf	27.0 s
Walk to/from blue cabinet from/to laboratory	34.0 s
Walk from/to pipe end (DS4 left side) to/from blue cabinet	3.2 s
Walk from/to DS4/5 control panel to/from 3-step ladder (in front of DS4/5)	3.2 s
Walk from/to DS17 to/from B/Y manifold	12.4 s
Walk from/to DS7 to/from B/Y manifold	9.7 s
Walk from/to DS4 to/from B/Y manifold	20.5 s
Walk from/to DS5 to/from B/Y manifold	22.7 s
Walk up/down a 1-step ladder DS7/17	1.6 s
Walk from grind sample point at DS17 to 1-step ladder (DS17)	1.6 s
Walk from/to 1-step ladder in front of DS17 to/from behind SK18	10.3 s
Walk up/down a 3-step ladder DS4/5	3.2 s
Walk from/to garbage bin to/from blue cabinet	5.9 s
Walk from/to garbage bin to/from 3-step ladder	4.9 s
Walk from/to garbage bin to/from DS4/5 control panel	8.1 s
Walk from/to garbage bin to/from sink	3.2 s
Walk from/to blue cabinet to/from interchangeable hose DS4/5 manifold	2.2 s
Walk from/to elevator to/from EGA885-pan on bottom floor	12.4 s
Walk from DS4 level measuring point to blue cabinet	3.2 s
Walk into elevator	3.8 s
Walk back to pan side of elevator	18.9 s
Walk up/down to/from elevator from/to elevator	41.6 s

Drag manual forklift out from elevator/walk back to close doors	3.2 s
Walk to/from in front of DS4/5 from/to elevator	10.3 s
Walk from/to the right side of pan (locking point) to/from M1-pipe connecting point	14.0 s
Walk from/to M1-pipe to/from T2	15.7 s
Walk from/to T2 to/from hardener manifold	14.6 s
Walk from/to forklift (in front of DS4/5) to/from DS4/5 control panel	5.9 s
Walk from/to DS4/5 control panel to/from nearest paper roll	6.5 s
Walk from DS4/5 control panel to DS4 pipe-end (left side)	1.6 s
Walk from/to outside elevator P2 lower level to/from outside wash area	67.5 s
Walk from/to 3-step ladder (DS4) to/from ullage storage	7.0 s
Walk from/to DS4/5 control panel to/from ullage storage	8.6 s
Walk from/to DS7/17 control panel to/from ullage storage (P2)	7.0 s
Walk from/to 1-step ladder DS17 to/from ullage storage (P2)	3.8 s
Walk from/to garbage bin to/from DS4-pan	7.0 s
Walk from/to 1-step ladder DS7 to/from ullage storage (P2)	5.4 s
Drive from/to D9 manifold to/from in front of DS4/5	20.0 s
Raise/lower forks to/from 2nd level in warehouse	10.3 s
Drive from/to liquid pre-batching to/from warehouse position O202 (where LX1 is located)	20.0 s
Drive from/to yard to/from B/Y/R manifold	68.0 s
Drive from/to B/Y manifold to/from DS17	10.0 s
Drive from/to in front of DS17 to/from powder storage	31.0 s
Drive from/to in front of DS4/5 to/from liquid pre-batching	54.5 s
Drive from/to liquid pre-batching to/from warehouse position D130	19.0 s
Drive out from pallet and position forklift beside it	10.6 s
Drive from/to "in front of DS4/5" to/from DS4/5 and raise/lower forks	31.4 s
Drive from/to yard with pan to/from in front of DS4/5	84.5 s
Drive from/to in front of DS4/5 to/from temporary powder storage	9.5 s
Raise pallet to ergonomic height	15.9 s

Fetch pre-weighed liquid pallet from storage to DS4/5	104.8 s
Drive out from/in under pan at B/Y manifold and park forklift outside P2	6.0 s
Transportation time liquid pre-batching storage to B/Y manifold	23.5 s
Transportation time liquid pre-batching storage to DS4/5	46.5 s
Move pan in/out under dissolver using forklift	8.2 s
Remove forklift from dissolver	5.0 s
Drive to/from pre-batched powder storage from/to DS4/5 (in front of)	30.5 s
Drive to/from temporary powder storage from/to next to 3-step ladder	12.0 s
Drive up next to 3-step ladder from in front of DS4	5.0 s
Transportation time liquid pre-batching storage to DS4/5	46.5 s
Drive in under pan with forklift (storage)	5.2 s
Driving out from liquid pre-batching storage with pan/pallet	6.6 s
Drive in under pan with forklift (storage)	5.2 s
Driving out from liquid pre-batching storage with pan/pallet	6.6 s

The second library of work tasks is not included in this appendix.