Development of a Headcount planning tool for a semiconductor factory

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Dissertation

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Abstract

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As a very dynamic industry, the field of semiconductor manufacturing is in constant development. Companies that operate within the industry are required to be both efficient in resource utilization and adaptable to new manufacturing technologies in order to stay competitive in the global market. This project was developed within the industry, specifically in operator headcount planning and allocation activities.

As operator headcount accounts for a significant portion of the overall cost of manufacturing it is necessary to ensure that operator numbers stay within the optimal levels. The project's main objective was to develop a specification to migrate the current spreadsheet based workflow to a web based application, as well as optimize the way that data is collected and updated by the involved departments. New visual reporting options were also added to simplify the way that the model's output data is interpreted.

To accomplish this, research was done to understand how other facilities within the semiconductor industry handle the headcount-planning task. A new data structure was developed in order to accommodate the changes made to the model's inputs and important variables were moved from static values to predicted values, following literature methods.

By analyzing how the different departments interacted to obtain the data fed to the model it was also proposed a new workflow that cut down on wasted time as well as ensuring that the data used is updated with higher frequency.

Research in other production line optimization methods resulted in more intuitive ways of displaying the results of the model.

Resumo

Sendo uma indústria dinâmica, o ramo do fabrico de semicondutores encontra-se em desenvolvimento constante. As Empresas que nela operam têm a necessidade de ser eficientes tanto em utilização de recursos como também adaptáveis a novas tecnologias, de modo a garantir que são competitivas no mercado global. Este projecto foi desenvolvido dentro desta indústria, especificamente dentro das atividades de planeamento e alocação de operadores.

Como o número de operadores representa uma porção significativa do custo total de fabrico, é necessário garantir que este se mantém dentro dos níveis ótimos.

O principal objetivo do projecto foi o desenvolvimento de uma especificação para permitir a migração do fluxo de trabalho atual, baseado em folhas de cálculo, para um baseado numa ferramenta online, bem como otimizar a forma como os dados são adquiridos e atualizados por todos os departamentos envolvidos. Novas soluções de apresentação visual de dados foram também adicionadas para simplificar a forma como os resultados da ferramenta são interpretados.

Para tal, foi realizada uma pesquisa de modo a compreender melhor como é que outras fábricas dentro da industria lidam com a tarefa de planeamento do número de operadores. Uma nova estrutura de dados foi desenvolvida de modo a acomodar as alterações feitas aos dados introduzidos no modelo e váriaveis de calculo importantes foram alteradas de valores estáticos para valores previstos, com base em métodos presentes na literatura de referência.

Analisando a forma como os diferentes departamentos interagem para obter os dados necessários para alimentar o modelo, foi também proposto um novo método de trabalho que reduziu o tempo alocado a esta tarefa, bem como garantir que os valores utilizados são atualizados com maior frequência.

A investigação realizada em métodos de optimização de linhas de produção permitiu o desenvolvimento de formas mais intuitivas de representar visualmente os resultados obtidos pela ferramenta.

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Content Index

Abbreviations

AGV	*Automated guided vehicle*
BPM	*Business Process Mapping*
ERP	*Enterprise Resource Planner*
F	*Financial Department*
HR	*Human Resource Department*
HRP	*Human Resource Planning*
IE	*Industrial Engineering department*
KPI	*Key performance index*
LBS	*Laser, Ball attach and Singulation*
MEMS	*Microelectromechanical System*
MES	*Manufacturing Execution System*
MMR	*Man-Machine Ratio*
OSAT	*Outsourced Semiconductor Assembly and Test*
PA	*Productive Area*
PCP	*Process Control Plan*
PE	*Production engineering department*
PL	*Planning department*
RDL	*Redistribution Layer*
UML	*Unified Modeling Language*
WLCSP	*Wafer Level Chip Scale Package*
WLFO	*Wafer Level Fan-Out*

Figure Index

Table Index

Equation Index

1 Introduction

This document was made under the scope of dissertation in business environment of the Master's degree in Mechanical Engineering – Production Engineering and Management. The project was conducted at ATEP- Amkor Technology Portugal S.A. with the purpose of developing a new headcount model and specification for the production line, to be implemented in the future in the company's planner application.

1.1 Company presentation

ATEP is a company that offers semiconductor packaging and testing solutions located in Mindelo, Vila do Conde. The company started as Siemens - Semicondutores S.A in 1996 and focused primarily on the manufacturing of cellphone memories.

Several name changes occurred during the turn of the century starting in 1999 to Infineon, a child company of Siemens meant to handle semiconductor related activities. In 2006, Infineon split creating Qimonda. The Portuguese factory was to be a part of this division. At that time, the factory was already manufacturing *wafers*, a technology still in use that allows a more efficient production, cost and chip size reduction. In 2009, following the world economic crisis, Qimonda filed for bankruptcy and the government and other banking entities bought the Portuguese division, changing name once again to Nanium, becoming the only one to survive the German group's insolvency.

The company faced several difficulties during this time due to being small in comparison to other major competitors namely in Asia where manufacturing costs where very reduced. It survived by investing in research and development of new packing solutions. Due to this it was able to attract the attention of Amkor Technology. Inc, which acquired Nanium in 2017, with the objective to gain access to their new Fan-Out technology.

Amkor Technology is an American company founded in 1968 originally in South Korea, a pioneer in the Outsource Semiconductor assembly and Test (OSAT) industry. Currently, the Mindelo factory is the only one located in the EU putting it in a pressured position to be efficient due to the reduced labor costs of Asian locations. Amkor stock is publicly traded in the NASDAQ stock market and reported annual net sales of 6 billion dollars in 2021.The acquisition process allowed the company to increase its market share and attract more clients and increase sales of the current ones.

Since the semiconductor industry is a technologically advanced and ever-expanding market, companies such as Amkor face the challenge of keeping continuous improvement strategies in both manufacturing and planning efficiency, in order to keep up with competitors.

1.2 Brief Product description

ATEP focuses in 2 main groups of products, Wafer Level Fan-Out (WLFO) and Wafer Level Chip Scale Package (WLCSP).To better explain both technologies, diagrams for these are shown in figure 1.

More recently it started expansion plans to allow the production of another type of product, Microelectromechanical Systems (MEMS). However, this last one is outside of the scope of this document as it currently has a different headcount planning model.

Both WLFO and WLCSP products start their life cycle as complete silicon *wafers*. Due to the nature of ATEP's business, their customers are also their suppliers of silicon, which means that all processed silicon is property of the specific customer. That is the reason why ATEP's classification is *service provider*. The final product is a complete integrated circuit ready for implementation in a variety of devices such as smartphones and automotive sensors.

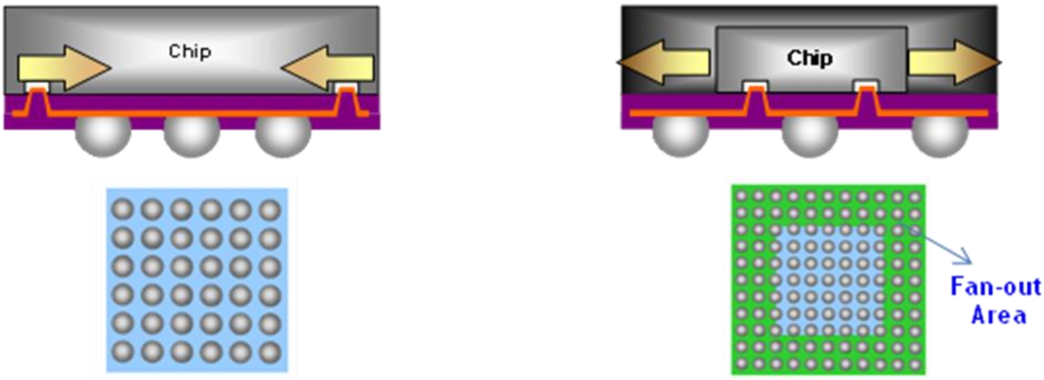


Figure 1 - WLFO and WLCSP technologies [18]

WLFO destined *wafers* go through a preparation process referred to as *WaferPrep*. In this step, the silicon disks are cut into individual dies. Throughout the process flow, several tests and quality assurance steps are made, such as automated alignment deviation detection, circuit checks using small electrical currents and visual defect detection.

Following *WaferPrep*, the individual dies are then used to build a reconstructed plastic and silicon wafer. In this step, the dies are individually picked and placed in an adhesive mold carrier in a specific orientation, followed by a polymer compound coating and pressed into the mold carrier. After removing the mold carrier, a plastic disk with several dies is obtained. This disk is now known as a *Recon Wafer*. This step usually allows for better utilization of factory resources, as it is often possible to include more dies in a recon wafer than in the original silicon wafer.

The next stage is designated as Redistribution Layer (RDL) and for WLCSP products, it is the initial stage of their process flow. This stage is divided into three areas: *dry*, *lithography* and *wet*. In the dry area, cures to ensure proper adhesion and mold properties are done as well as several cleaning processes to prepare the *wafers* for the next steps. In the lithography area, a dielectric material, known as photoresist, is used to coat the wafers, which are then exposed to ultraviolet light with a specified pattern. The exposed zones are then removed with the use of a developer revealing the channels that are intended to be filled with conductive materials, which will make the interface between the chip and the intended device. The next step, *wet*, is to add these conductive materials to the *wafers* using a process known as sputtering, a physical vapor deposition technic, that allows the deposition of metallic materials in the micro scale. These steps are repeated several times to build the full 3D circuit of the chip.

The final stage of the process is designated as Laser, Ball Attach and singulation. (LBS). In this stage metallic conductive balls are soldered in specified points of the chip. These are the points that will be in direct contact with the intended device. The backside of the *wafers* is then laser marked according to the client's specification and finally the *wafers* are cut into individual chips, packed and shipped to the costumer.

1.3 Project Objectives

The main objectives of the project where to develop the specification of a new headcount model for later implementation, as part of the company's planner tool and to standardize the time collection process as well as the way that the data was added to the model.

The project was developed at the department of planning and logistics of the Mindelo's factory. The reason for its development came as a result of resource utilization inefficiencies, that would lead to wasted time in activities that could possibly be automated.

The way that the company made its headcount calculation was based on several spreadsheets with data related to different products stored in them that needed to be manually input and updated, which lead to several weekly hours spent in the process.

In addition to this, the way that data was collected was made by a request system, where specific times were only measured after a request was made, which would not ensure that the times fed to the model where up to date.

1.4 Methodology

Due to the complex nature of the industry the first weeks were dedicated to learning the processes of the company and also what were the responsibilities of all the members of the planning department. This was necessary to better understand how the model should be designed.

The next stage of the Project was dedicated to better understand the problem and to define what where the needs of all the departments involved. This also allowed for better understanding of the model that was currently in use. This resulted in changes to the model workflow which were also defined.

After this research, a new data structure was developed in order to accommodate the needed alteration for the model. This process required several iterations as some connections needed to be added and removed.

With the completed data structure it was possible to start defining how the calculation process should be handled and design mock-ups where made in order to allow easy comprehension. Some constraint variables were also changed from static values to automatically updated predictions based on recorded values.

1.5 Dissertation structure

This dissertation is divided into 5 chapters. In chapter 2 a literature review related to headcount and human resource planning concepts in general and related to the semiconductor industry is presented. Furthermore, a brief explanation of some of the tools and methodologies used is made. In chapter 3 the current process is explained in terms of department activities, data storage, calculations and also process limitations and improvement opportunities. In chapter 4 the proposed solution is presented in detail. Chapter 5 focuses on visual display solutions that were proposed as well as the expected results from future implementation. Finally, in chapter 6 conclusions and future work opportunities are presented.

2 Literature Revision

In this chapter, all major research on topics related to the project and that also guided the decisions made in it are described. Section 2.1 refers mainly to general definitions and concepts related to headcount, manpower planning and process analysis methodologies. Section 2.2 refers to techniques and methods that were used or adapted to form part of the final tool proposal.

2.1 Headcount and business process concepts

This section is composed by all the sources of information that concern business management and it's relation to headcount planning as well as general process optimization strategies and tools. Each concept is presented and summarily explained and also it is made reference to it's application in the different industries.

2.1.1 Headcount and human resource planning

Human resource or manpower is a primary resource without which other resources, physical and financial, cannot be put into use. Even a fully automatic unit requires manpower to be ran and also to plan for further improvement [1]

As [1] explains "optimum manpower planning aims to balance demand, supply distribution and allocation of manpower". Human resource planning (HRP) is not a mere assessment of the number of operators required to operator a factory's machines. An improper allocation or deficient acquisition of operators will likely result in over-staffing, which will in turn result in an increase of the direct cost of the process, as well as increased training and amenities costs. The opposite is also possible with under-staffing leading to inability to comply with production deadlines, increased number of injuries related to overworking along with low team morale and productivity.

HRP consists of a series of activities, such as forecasting future manpower requirements, which is done by either using mathematical projections based on current trends, economic environment and known demand or by estimation based on previous experience.

Anticipating problems with manpower is also an important activity, which requires projecting the current level of resources into the future and comparing them with the available headcount level. Changes are made in accordance to headcount number or operator certification.

Finally, meeting manpower requirements is the stage that directly puts in contact the future operator and the company. Recruitment and selection as well as development, induction and future career progression need to be met to ensure success of both Employer Company and employee.

2.1.2 Human Resource Forecasting

To start the recruiting and training procedures a credible Forecast of the total number of operators should be available. In order to obtain that Forecast, first it is necessary to have a good enough understanding of the process needs in terms of operator time. The way this process time attribution is made changes from industry to industry, while some prefer a quick rule of thumb, others might require a higher level of precision when attributing operator needs to a process [3].

For the most part this decision comes down to two factors: how heavily the headcount costs factor into total company revenue and the qualification levels that company processes require.

In the majority of the semiconductor industry, the main concept that serves as a base for many models for headcount planning is the concept of man-machine ratio (MMR). This method assumes that for a specific process with a given number of steps and machines required for its completion, a given number of operators is also required [7]. The ratio of number of operators required and total machine available time is known as man-machine ratio. Having knowledge of these ratios for all the processes done in a given factory, and knowing how much production time is available for a given week it is possible to obtain the number of operators required to keep the factory working. This forecasting process is simple enough to obtain and to maintain after collecting the initial ratios, which is a more time consuming task.

All decisions made should be in attempt to reduce these ratios and to ensure that proper headcount levels are maintained. A common problem with this kind of implementation is it usually tends to result in over-staffing situations. Due to the simple nature of the base concept other factors such as absenteeism or volume fluctuation effects in production time are not considered [10,11].

Another approach is starting to be integrated in some industries. This approach is also step based, but instead of looking just at the number of operators per step, it looks at the specific time that an operator needs to complete said step for a given production lot or unit. In addition, the amount of work time available for an operator in a week, taking into account all predictable and unpredictable stoppages also needs to be factored.

This is results in very resource intensive practice. Not only to make an initial collection of said times, but also for every new product added to a given production line. In return a much more sensitive model is obtained, one that, if regularly updated, can determine the operator needs with much higher accuracy.

The trade-off point between the two types of solutions is directly linked with the variety of products a factory produces. Higher variety of products offered means more step times need to be collected for proper output results which may not be as beneficial as if the time dedicated to these measurements were to be dedicated to process improvement. On the other hand this is trade-off is also related to the total volume a factory intends to output. This is due to the manpower requirements decreasing as volume needs decrease, as in the case of product rollouts. For these situations an estimation is needed based only on what the equipment information has available, as there is no way of measuring how much time operators need in before starting production and operators need to undergo certification and training in order to use new equipment safely. In conclusion, for both high diversity of products and for initial low volume production an MMR based model is usually necessary.

2.1.3 Company Standard

Amkor as a company holds monthly e-meetings where all of the group's factories participate with the intent of sharing practices and improvement. One of those meetings had as a main theme headcount management. From that it was possible to understand how other factories' models work.

All other company sites in Asia use a MMR based model in the same shift rotation system, and monthly comparisons are also made to insure that process efficiency is shared across all facilities.

ATEP is currently the only one using a step-based model for operator headcount, which made it stand out as the headcount output results tended to result in lower over-staffing. Several of the other sites mentioned that they wanted to try and replicate similar solutions.

It is important to note that for a factory with a high variety products this process represents a very high investment, so many want to only implement it on smaller sections of production as a start. The other situation where a MMR model is a more suitable solution is at the start of a new production line, where different products are in the initial stages of production and also times are not collected for all of the process steps. In this case, there is not enough data to feed a step time based model. This is the current situation for the MEMS production line, that is finishing the testing and low production phase with the aim to start continuous manufacturing in the first quarter of 2023. Within the planning department's strategy is to also move the MEMS headcount model to a step-based one as production levels stabilize.

2.1.4 Under and over-staffing costs

Despite being an ever more automated field of technology [15], the semiconductor back-end industry can still benefit from cutting down on unnecessary over-staffing as well as the consequences of working with a lower than required number of operators.

In the case of over-staffing, excess costs are result of unused operator time whereas in under-staffing situations, the main costs result in direct compensations to employees relating to working overtime and medical expenses associated with overworking.

The presence of overtime increases the possibility of human error occurring, because of that, it is of no surprise that the major cost that is linked to insufficient staffing is client compensation for missed deadlines or the delivery of defective units, which can result in significant cuts to a company's bottom line [16,17].

In order to be in the safer side of the over and under staffing problem, most companies tend to try to remain slightly over-staffed, as this case ensures a higher probability of order completion, as well as reducing the possibility of errors. This is one of the reasons why semiconductor companies tend to adopt MMR based models, as mentioned in section 2.3[11]. Nonetheless, a case can be made that correctly approximating workforce needs will still result in significant company savings and if done correctly will not incur in added risk of under-staffing costs.

2.1.5 Business process mapping and digital workflow implementation

To be able to successfully improve a given process or workflow, it is necessary to fully be able to define it, and for this, three sets of information need to be gathered: The tasks that need to be complete, what means or tools are needed to complete said tasks and who are the people responsible for executing the tasks. These sets form the base form which business process mapping (BPM) occurs [22].

BPM consists in both collecting and displaying the sets of information previously mentioned. For collection, the starting step is to define what is and what is not a needed task or activity. For some processes, namely those related to a production line, this definition is closely related to what is known as value-added and non-value-added activities, which are necessary for a product to be complete. On the other hand, for processes related to services or office related activities this definition can sometimes be difficult to obtain.

For displaying , the use of different kinds of relationship maps can be used, such as the cross-functional process map or swimlane diagrams. Both of these display the connection between a task and the person or entity responsible for it's execution, as well as highlighting the sequence that tasks should follow or any possible parallel tasks that can be done. This kind of representation is also used to ensure that task accountability and responsibilities are well laid out, reducing errors due to lack of knowledge or wrongful task attribution.

BPM often times also serves as a general way to organize how a company strategy is to be followed. This is usually done in several levels through diagrams, that represent general ways or philosophies of action, namely ones related with overall quality assurance or business improvement. At ATEP these are applied across all collaborators of all departments and serve as a guide for overall decision making. These strategies and maps are then be broken down into effective tasks or objectives, and have responsible departments identified. This funneling of information ensures that the work being done is in line with the company's strategic plan.

Besides the need for BPM, in a globalized market with newer versions of both hardware and software capabilities available, there is also a need to ensure that these resources are used to their full potential. To do that, many companies have made significant investments in modernizing their current way of work by transferring manual task to web-app based solutions.

As stated in [20], companies that operate in highly regulated industries, such as the case of the semiconductor industry, have a further challenges to the usual competition. To handle these needs companies optimize their business processes and change their software and information systems to allow for evolution in the way of doing business.

Technologies related to workflow management provide methodologies, applications and tools which support business process modelling. Business Process Mapping is essential to completely capture the way a process workflow is specified and to ease software implementation and future of integration of said methodologies in the companies.

A collection of challenges and benefits of this type was obtained for the case of aerospace manufacturing[20], which operates with tolerances close to that of the semiconductor industry.

The main benefits found were related with improved efficiency, reduced number of errors, streamlined processes and improved communication. The main challenges were the complexity of process definition, resistance to change, difficulty ensuring management engagement in the process, among others. Besides pros and cons a set of success factors are also cited which are mainly related with ensuring that every department is sufficiently involved in the specification process and that the implementation is done in phases and not as an abrupt change in workflow.

2.1.6 Key performance indicators

The companies with large global market impact have realized that, the more information sharing capabilities were made available to the general public, the harder it became to stay competitive within their areas of business. This fact lead many to come to the realization that in order to excel and out-perform their competition they needed to also excel in project management. It meant that every improvement opportunity needed to be tackled, but in order to identify these opportunities they needed ways to better measure what their processes performance was. Not only by time measurements and defect rates but also by identifying which of these units would result in higher profitability.

As stated by [23] ,"The ultimate purpose of metrics and dashboards is not to provide more information but to provide the right information to the right person at the right time". An information system that simply outputs measured values is of little significance to both managers in charge of decision making and to the company's stakeholders. So, care needs to be taken when choosing which of these values matter, how they are obtained and how they should be displayed.

The majority of modern dashboards display items that are referred to as key performance indicators (KPI) they represent a metric that measures "how well an organization or individual performs an operational, tactical or strategic activity that is critical for the current and future success of the organization"[24]. The main difference between a traditional metric and a KPI is that a traditional metric is focused primarily on completions, milestones or progress achievements, on the other hand indicators are focused on future outcomes. As decision making is based on what is to happen and not what happened in the past, it is for this reason that the values shown to managers and board members should be KPIs.

Although better suited for correct prediction, neither KPIs nor metrics can truly predict whether a project will be successful, the real objective is to provide the most accurate context for what might happen in the future based on the current trends.

There are also different categories of KPIs depending on what they intend to indicate, for the majority of sources these are: *quantitative*, referring to a numerical value; *practical*, when they interface with company processes; *directional*, if they indicate that an activity is getting better or worse and *financial*, to signal performance measurements. Most dashboards are assembled using combinations of different categories of these indicators.

Correct use of KPIs ensures that management decisions are made simpler, as the correct path of action is already present in the definition of an indicator, so tactical choices are also put in motion sooner.

2.2 Methods and techniques used

In this section, the main practical tools and methods that were used or adapted as part of the new tool are presented. Along with this, the reason for their utility to the project is also elaborated upon.

2.2.1 UML and Data modeling

In order to better convey the data storage and display needs to the company's IT team a version of the UML language was used. UML or Unified Modeling Language is a visual modeling language that is the universal standard used for software specification. Its conception was result of an effort to unify several different languages used in the 90's [2]. As it as flexible tool, it can be used with varying degrees of complexity depending on the intended reader.

The use of class diagrams significantly streamlines the description of how the data used in a information system should be inter-connected and the different rules of how the stored data should be processed. It is good practice, when implementing data system conversions, to reevaluate what information is relevant and necessary while taking away any unnecessary values. This can be done by first defining the new data structure in UML format.

2.2.2 Yamazumi charts

As a process improvement technique that is used by other departments in the company, the yamazumi charts method was the most relevant in terms of ease of visual interpretation.

Yamazumi is a Japanese word that roughly translates to "stacking up". The produced charts make use of vertical bars to represent the total amount of time an operator needs to complete a given task and how this amount compares to the process duration needed to match costumer demand, a concept known as takt time [5].

The process of obtaining a full yamazumi chart involves firstly the definition of all the required tasks needed to complete a certain project, be it a product or service, in a sequential manner. Afterwards, these tasks should be sub-divided and categorized as activities of added value, non-added value or waste.

The next step is to obtain the total available work time per week, the deliverable units that are expected and finally to calculate takt time with these values. Continuing, the method now requires that measurements are made for each activity.

Finally the full chart can be generated by stacking all activities into bars and placing these sequentially from left to right. An example of this type of chart applied to the textile industry is shown, in figure 2, for the production cycle of a casual shirt.

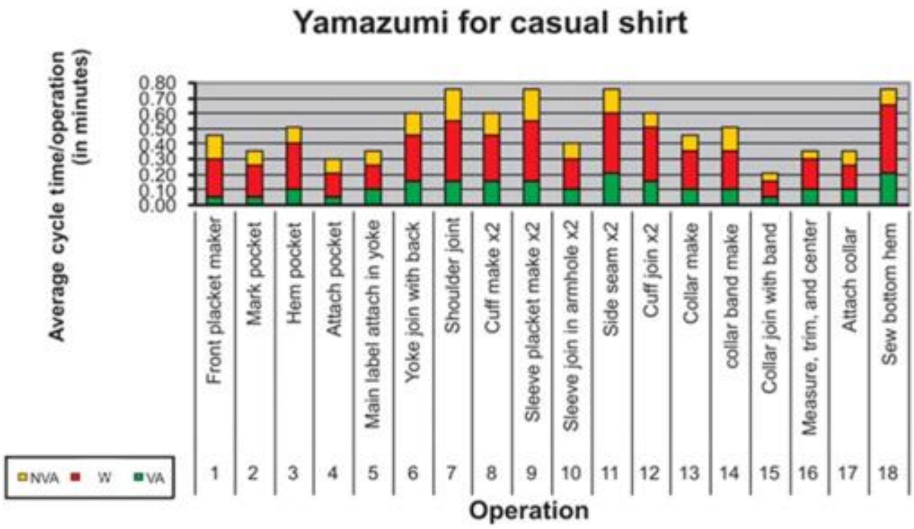


Figure 2 - Yamazumi chart example in the textile industry [5]

The two main goals of this visual display is to quickly identify which process or processes are outside of the required takt time and from a given process what are the activities that should be tackled first by process improvement strategies.

2.2.3 Prediction methods and technics

One of the main goals of the new solution implementation is to make the model's results closer to meeting the needs of the production line. For this ,constraint values present in the model are required to be predicted with a certain degree of confidence. In this case, it is a matter of generating a predicted value based on a chronological series of previously observed values [4]. A chronological series is defined to be a series of values relating to a given variable, that is measured in equidistant periods of time, such as monthly values for operator absenteeism.

By analyzing how a series behaved in the past, such as if relevant seasonality is present or an increasing yearly tendency, it is possible to make an educated guess, based on statistical tools, of the next value of the series. This type of predictive analysis method is usually present in sales demand prediction or asset price prediction. Due to the chronological nature of the series, the same models can be applied.

Some of these techniques, such as the simple average method, require all historical values be present in the prediction calculation. However, there are others that only require historical values in order to start the process and can be maintained by simply updating the prediction formula with the new measured value, such as the case of the exponential smoothing method. This last method was the one chosen and uses a recursive algorithm that is described in more detail in chapter 4.

Other techniques analyzed as possible for the current solution were the double exponential smoothing and the moveable averages method [4]. The double exponential smoothing is an evolution of the exponential smoothing method that applies the same recursive algorithm to the input values used to start the calculation. As for the moveable averages method applies a simple average that moves along a set number of the previously observed values and updates the series by adding a new, predicted, value and by removing the oldest observed value. The reasons for opting between the different methods are described in chapter 4.

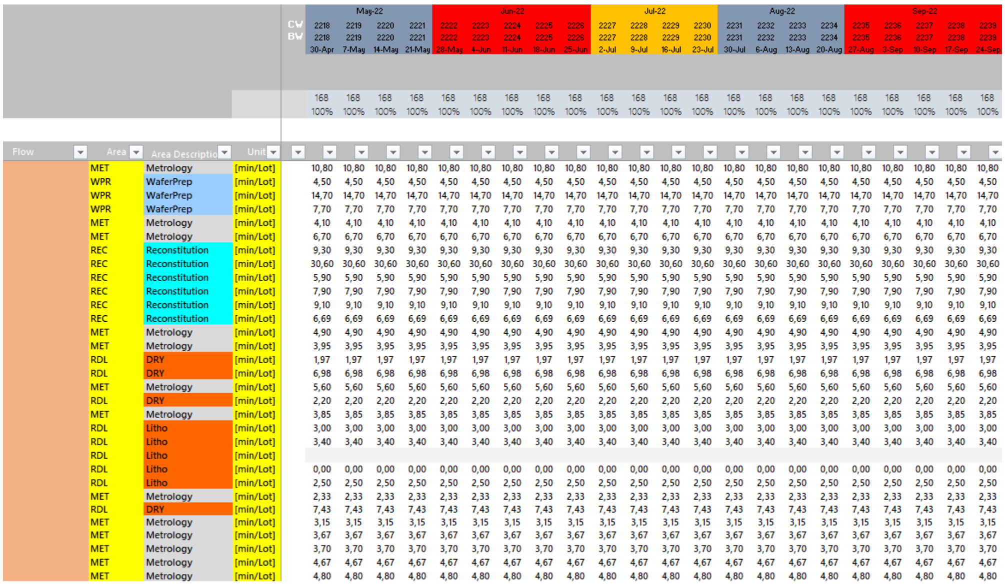
3 Current Headcount model description

In this chapter, a description of how the problem is currently handled by the company is made. Moreover, concepts used in headcount calculations are presented as well as the current limitations of the model.

3.1 Current methodology

Currently in the planning department, the majority of the calculations and data processing are being done using spreadsheets. A screenshot of one of the spreadsheets is shown in figure 3. For headcount, capacity needs and also weekly volume demand distribution the same structure is used varying only the type of units used.

An effort is being made to move all of these to web-based applications. The capacity calculations already have a web-based version that is being brought up to date in terms of data stored and possible calculations.



					May-22				Jun-22					Jul-22				Aug-22				Sep-22				
				CW	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239
				BW	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239
					30-Apr	7-May	14-May	21-May	28-May	4-Jun	11-Jun	18-Jun	25-Jun	2-Jul	9-Jul	16-Jul	23-Jul	30-Jul	6-Aug	13-Aug	20-Aug	27-Aug	3-Sep	10-Sep	17-Sep	24-Sep
					168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168
					100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Flow	Area	Area Descriptio	Unit																							
	MET	Metrology	[min/Lot]		10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80	10,80
	WPR	WaferPrep	[min/Lot]		4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50	4,50
	WPR	WaferPrep	[min/Lot]		14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70	14,70
	WPR	WaferPrep	[min/Lot]		7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70	7,70
	MET	Metrology	[min/Lot]		4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10	4,10
	MET	Metrology	[min/Lot]		6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70	6,70
	REC	Reconstitution	[min/Lot]		9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30	9,30
	REC	Reconstitution	[min/Lot]		30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60	30,60
	REC	Reconstitution	[min/Lot]		5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90	5,90
	REC	Reconstitution	[min/Lot]		7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90	7,90
	REC	Reconstitution	[min/Lot]		9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10	9,10
	REC	Reconstitution	[min/Lot]		6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69	6,69
	MET	Metrology	[min/Lot]		4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90	4,90
	MET	Metrology	[min/Lot]		3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95	3,95
	RDL	DRY	[min/Lot]		1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97
	RDL	DRY	[min/Lot]		6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98	6,98
	MET	Metrology	[min/Lot]		5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60	5,60
	RDL	DRY	[min/Lot]		2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20
	MET	Metrology	[min/Lot]		3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85	3,85
	RDL	Litho	[min/Lot]		3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00
	RDL	Litho	[min/Lot]		3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40
	RDL	Litho	[min/Lot]																							
	RDL	Litho	[min/Lot]		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	RDL	Litho	[min/Lot]		2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50
	MET	Metrology	[min/Lot]		2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33	2,33
	RDL	DRY	[min/Lot]		7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43	7,43
	MET	Metrology	[min/Lot]		3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15	3,15
	MET	Metrology	[min/Lot]		3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67
	MET	Metrology	[min/Lot]		3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70
	MET	Metrology	[min/Lot]		4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67	4,67
	MET	Metrology	[min/Lot]		4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80	4,80

Figure 3 – A example of one of the model's current spreadsheets

The headcount calculations are done with less detail than the capacity or material needs ones and primarily have a medium to long term scope. This is mainly because the operator headcount values are much more stable to comply with labor and employee protection laws, as well as the time needed to complete recruitment processes, which is usually of 3 weeks per operator. For this reason, the model's range for planning is of 3 to 6 months in the future.

ATEP, recently moved from a MMR based model to a step-time based model. This required coordination between several departments. The Planning department (PL) is mainly responsible for updating the times used in the model and interface with the Human Resources department (HR) about the model's output. The industrial engineering department (IE) is responsible for most time measurements. Finally, the Production Engineering department (PE) is responsible for step-time requests and for notifying of process flow alterations. A weekly meeting is held, where members of each department exchange their respective results and needs. If a step-time needs to be updated this is done manually by the PL department, replacing the respective value in the model's spreadsheet. This process is also the same for adding new step-times to a given product, adding or updating sampling values of a given step or adding a new product to the model.

3.2 Headcount calculation inputs

To clarify how the headcount values are obtained, it is important to define what inputs the model uses. The main input is process step times, which amounts to the total time an operator needs to complete a given step. Due to the automated nature of the factory, the majority of value added activities are not handled directly by an operator and for this reason, process time as is usually defined is not relevant for operator headcount of the company.

At ATEP, an operator can be responsible for the transport of the *wafers* from one machine to the other, process control and also logistics or documenting activities. To simplify the time collection process, these times are categorized. Times related to wafer carrier transport are designated by F1, times dedicated to process control are designated by PCP (Process control planning) and the remaining times are designated as Extra (Extra activities) such as reel changes, blade changes and reporting. A set of activities included in these categories is shown in the figure 4 diagram.

A product is completed by following a series of steps to which a time value is assigned, in units of minutes per lot in the different categories described previously.

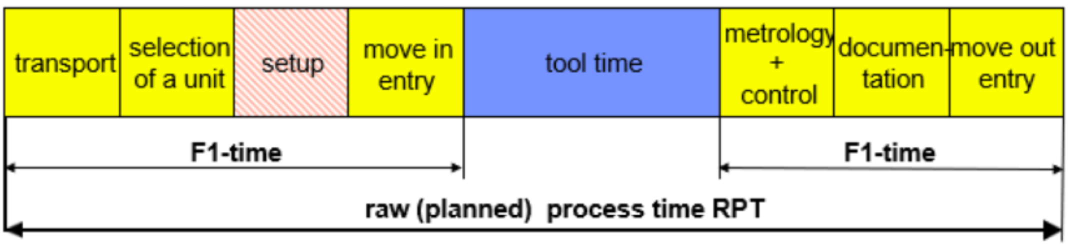


Figure 4 - F1 and PCP time diagram (from an ATEP capacity planning presentation)

The next input is weekly volume demand for each of the products manufactured. For this, the planning department makes updates during the week to a spreadsheet that is linked to the model. The values stored in this file are in wafer units expected to be completed for each product. The demands vary from costumer to costumer but tend to stay within a 2 year in the future scope and are adjusted according to equipment capacity and material availability.

Lastly, the model needs information related to time constraints. These primarily affect the amount of available time an operator has assigned, usually in the form of a percentage value that is subtracted from total shift time but also refer to lot sampling percentages, mainly for inspection steps.

3.3 Headcount calculation

With the knowledge of the different variables it is possible to show how the operator headcount value is obtained for a given week.

3.3.1 Time per Shift

Different products are handled either in lots of 25 or 12 *wafers* depending of the process nature. Some products, however, may have a reduced lot number, especially when production of that kind of product has started recently (ramp-up period) or a newer version is being tested. For this reason an average lot size is calculated using the following formula:

$$Average\ lot\ size[\frac{Wafers}{lot}] = \frac{\sum(Volume[wafers] \times Individual\ lot\ size[\frac{wafers}{lot}])}{\sum Volume\ [wafers]}$$

Equation 1 - Average lot size

A product's demand volume is multiplied by the respective lot size. This is done to all products. Furthermore, the sum of all calculated values is divided by the total volume demand of all products.

The next step in the calculation is to apply lot-sampling percentages to each step. For the most part the sampling value is kept at 100%, except for inspection and measurement steps where only a given percentage of the total lots is processed. Sampling is applied by multiplying the sampling percentage and step-time value. Afterwards, the total time is calculated using the following formula:

$$Time_{week}[h] = \sum(F1 + PCP)\left[\frac{min}{lot}\right] \times \frac{Volume[wafers] \times WaferSamp[\%]}{lot\ size\left[\frac{wafers}{lot}\right]} \times LotSamp[\%] \times \frac{1}{60}[\frac{h}{min}]$$

Equation 2 - Total week time PCP and F1

This is repeated for all products and summed. The final value is rounded up and divided by the number of shifts to obtain the total time per shift. Extra activities follow the same logic but instead of being linked to a flow it is linked to the area where the activity takes place. The calculation formula follows the same logic of the previous one, a can be seen in equation 3.

$$Time_{week}[h] = \sum (Extra)[\frac{min}{shift}] \times \frac{1}{60}[\frac{h}{min}]$$

Equation 3 - Total week time Extra activities

3.3.2 Operator available time

As manufacturing is done in a rotating shift structure, all 168 hours in a week are considered as available time. Currently there are two, 12 hours, shifts per day.

The constraints that affect the total available time are, assigned break time, a recovery factor that considers all unscheduled operator stoppage, an operator absenteeism factor that also includes holiday time and also an engineering support and monitoring factor.

All of these factors are subtracted from the weekly available time to obtain the total operator available time.

3.3.3 Total Operator needs

The final calculation to obtain the number of operators is to divide the time per shift, defined in section 3.3.1, by the available operator time defined in section 3.3.2 and rounding up the obtained value, as per equation 4.

$$Nº\ Operators = \frac{Time_{week}[h]}{Operator\ available\ time\ [h]}$$

Equation 4 – Total operator needs

This process is done for all products and separated into the different production areas of the factory.

In addition to the calculated value of operators, there are also some operators that are directly assigned as area supervisors, as well as some that are allocated to process development activities, such as helping with Automated Guided Vehicle (AGV) implementation. These are referred to as additional operators and are specific to the needs of the production line.

3.3.4 Extra Activities

In section 3.3.1, extra time is treated as always being in minutes per shift, but in reality this value can sometimes be measured in a different unit. For that reason conversion formulas are defined for these cases.

The first conversion is when the step-time measurement is done in minutes per lot instead of minutes per shift. The calculation in this case is done by multiplying the total lots processed in the productive area by the time required per lot.

Another conversion is done when the time is dependent on the volume processed. Measurements that rely on the total volume of *wafers* being processed, such as reel or blade changes follow the structure of the formula presented in equation 5.

$$\text{Extra time} = \frac{Total\ Volume}{Change\ Frequency} * Change\ Time$$

Equation 5 - Extra activities conversion formula structure

The main difference between these activities is whether they use total volume in Silicon or *Recon Wafers* and what the change frequency value is.

3.4 Model Limitations

Although it has a higher level of fidelity when compared with MMR based models, as was evidenced in chapter 2, the current solution still has limitations.

In terms of usability the fact that the whole model is based on spreadsheets makes the task of updating time fields of all the steps, time consuming and monotonous and it is made worse when steps are either added or removed, as there is not currently a way of signaling all the departments that these changes occurred. The same happens when a completely new product is added to the model, and results in long periods where the information present in the model is not accurate.

The current workflow requires a weekly meeting between the industrial engineering, production engineering and planning departments where the new product times sent via e-mail are confirmed and new requests are made. After the meeting, the times are individually added to the model, as can be seen in the diagram of figure 5.

It is estimated that at least 1 hour is needed to be allocated to each department per week to ensure proper model update. Many times due to other work related factors, the meeting is postponed often leaving uncertainty as to status of the times fed to the model. Furthermore, sometimes other departments or other facilities within the company may request the impact that a certain product on the overall headcount has, for example when deciding whether to add a new step to a current process or not, an analysis of the impact on the headcount levels is usually made. With the current model, it is necessary to manually change all the step-times of other products to zero and copying the results to a different spreadsheet for further reporting.

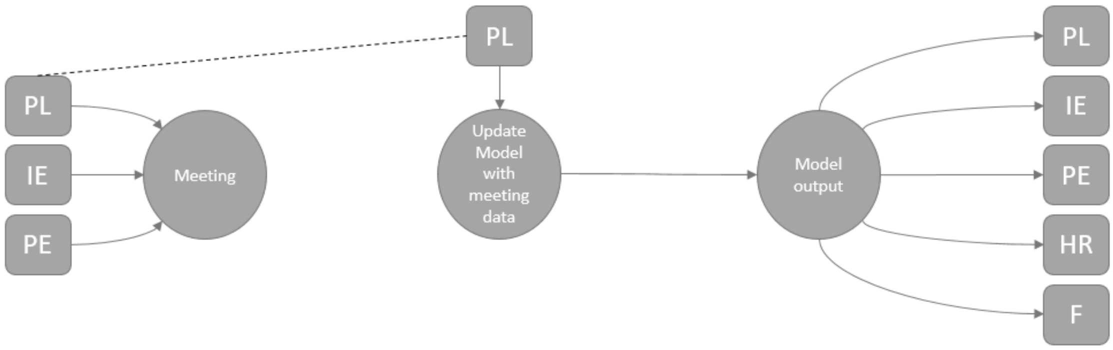


Figure 5 - Current model workflow

As for the model's constraints, they are currently handled as static values, which is acceptable for cases where these values are supposed to be static, such as number of shifts per week or percentage of time allocated to breaks. However, in the case of absenteeism or engineering support factors, these have the possibility to be modeled using prediction models or functions of other values rather than fixed values.

There is also a limited number of visual reporting solutions, as it must follow the pre-defined format of charts that the spreadsheet software allows. In addition, there is currently no easy way to make simulations of future changes, as this would require manually updating constraint values for several weeks. Due to the way that the software works over a network it is not possible to have more than one editable version open at a time.

4 Proposed Solution

In this Chapter, the proposed solution for the new headcount tool is presented in a subdivided manner relating to all major stages of the specification document development. This chapter follows the same structure as the document presented to the company and only sensible data has been edited or replaced by examples.

4.1 Solution Objectives

The main objectives asked by the involved departments for the headcount planning model web application are as follows, presented in order from higher to lower priority:

- Reduce the amount of time dedicated to inserting step time updates
- Simplify the amount of data being recorded by the model
- Increase the depth of the model's scope
- Improve the model's constraint value calculation
- Allow for added visual representation of data
- Allow for parameter variation for forecasting purposes

The major changes are intended to affect the tool's workflow, while adapting the already existing method of calculation. In terms of the way that the tool calculates the operator needs, this closely follows the methodology described in chapter 3. By controlling the main constraint variables it is possible to guarantee predictions closer to the truth, without the need of altering the calculation formulas, as per request of the involved departments.

4.2 Data Structure

As a primary base for all information storage, a well-defined data structure is key for a successful implementation of any online data storage tool. For that reason the starting point was to define how the information supplied to the model was going to be stored and which of the currently stored data was of no use for the tool. To add to this, it was also necessary to evaluate the data that was already being stored by other tools, namely the ones related to capacity planning, to ensure that information is not stored in multiple locations.

By analyzing the capacity planner tool, overlapping information related to the current headcount model was identified, namely the way that a product cycle is defined and how step times are attributed to it. By taking these findings into account as well as inputs from the meetings with all of the involved departments a UML class diagram was developed, to serve as a base for the IT department implementation. The development of the class diagram is shown in the following paragraphs.

The main information input of the model, as was already explained, are process times related to a specified step, which need to also be linked to a specific week of the year in order to allow for correct interface with the Weekly volume plan structure currently being used. One of the steps main attributes is its Stepname, which is just a simple string that identifies a specific step. This is used in several other tools so maintaining it ensure easier comprehension.

Steps, in the company's manufacturing execution system (MES), are bundled in routes and enterprises. An enterprise is dedicated to a given product and is comprised of several routes, which are a series of steps that identify a certain stage of the process and that could be shared with many products. For example, all WLFO products follow the same routes at the *waferprep* stage, but depending on customer requirements on product might need to follow several steps related to quality control before advancing onto the next stage. This would mean adding a route to that specific product enterprise.

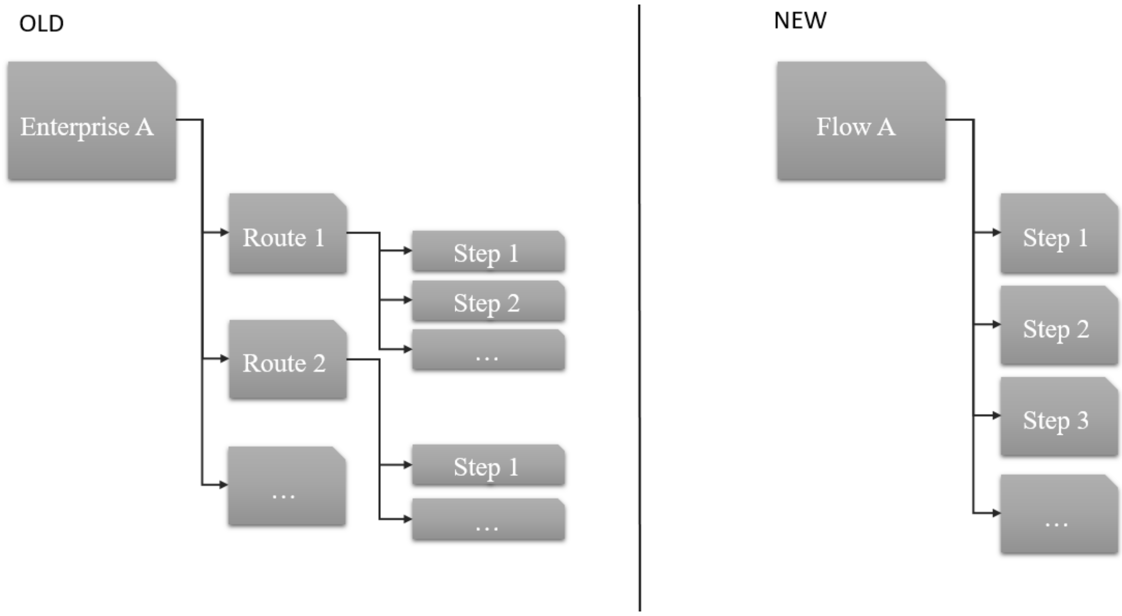


Figure 6 - Enterprise to Flow structure

However, for headcount needs this separation is currently not required, as in the case of other departments. So a simpler definition should be used to bundle product steps. A full product factory cycle should be defined as a flow. Each flow being comprised of a sequence of all the steps currently present on an enterprise, as shown by the example in figure 6.

To identify a flow in the headcount tool a key (HCkey) should be defined and the naming rules for a given HCkey are related to the already existing keys, namely the capacitykey parameter that is used for the same purpose by the capacity tool. This key is not automatically generated and is instead named by the capacity planners in accordance with planning needs but always has the same structure, starting with type of technology followed by an internal costumer identifier, a product identifier code and followed by any process related information seen fit.

The capacitykey usually has more information than is required for the headcount model, as it can present process related identifiers, such as the thickness of the silicon wafer used and can differ for the same product, which directly affects processing time. As these identifiers relate to value added activities they present a level of differentiation that does not have direct impact on operator activity time.

For that reason when adding a new flow to the model the HCkey should be a shortened version of the capacitykey of the same product, without the process related information. A structure example is shown in the figure below.

CapacityKey = Technology+Costumer+ProductReferenceString+ProcessIdentifier

HCkey = Technology+Costumer+ProductReferenceString

Figure 7 - CapacityKey and HCkey structure comparison

This flow structure, groups steps and also stores information shared by all them. The attributes given to a flow are shown in figure 8

The FlowName attribute is where the HCkey is stored. The costumer attribute stores the customer name to which the product's flow belongs. The type attribute refers to the technology product is included on and serves as an identifier to the type of wafer unit that is used. Related with type, the Si/Rec attribute is a conversion factor, currently for WLFO products, relating the number of Silicon *wafers* needed to form a Recon wafer. This value is stored for all products in case future technologies follow a similar format.

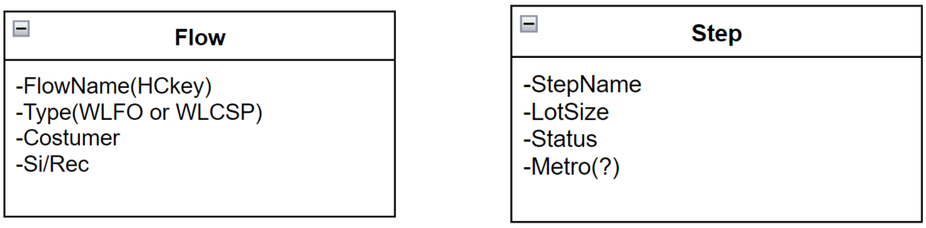


Figure 8 - Flow and Step Structure blocks

The step structure has attributes that are related to a specific step. StepName stores the individual step name and is based on the current naming rules of the company, which try to be closely related to the process, for example *grindwafer1*, is the step name for the first grinding of a wafer.

LotSize identifies the number of *wafers* that are processed in each individual step, this is done because within the same flow some steps can use a smaller lot size. The status attribute is a boolean value an serves to identify if a step has ever been assigned a non-null value. The metro attribute is also a Boolean value that identifies if the step is a metrology related step. Even though most metrology steps are done in an assigned area in the factory, some smaller visual inspection steps are also made in some of the other areas. For reporting needs this makes it easier to filter through these steps.

The next structure to be defined is the production week. This structure is identified by an integer that concatenates the year and week (yyyyww) and should be maintained to allow correct linkage with the weekly plan structure. The attributes for this structure are shown in figure 9.

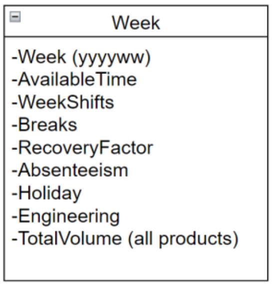


Figure 9 - Week Structure block

The AvailableTime attribute is an integer that represents the weekly available time in hours, usually 168, but changes in holiday season such as Christmas to a lower value. The WeekShifts attribute stores the number of weekly shifts. This is currently a fixed value but is stored in case future changes are made. The TotalVolume attribute stores the total number of Silicon *wafers* to be processed for all products, which is done because of extra activities that are volume related.

Another type of information that is also stored by this structure are the constraint factors. Breaks stores the value of approved and mandatory break time. Recovery stores a value relating to any breaks that are not predictable, usually emergency needs. Absenteeism stores the value related to unplanned operator absences. Engineering support stores the factor relating to monitoring time dedicated to engineering activities. The holiday constraint factor was added to the model to allow for separate handling of absenteeism and holiday factors.

The time values need to be connected to a respective step and week as well as additional information. F1 and PCP times are stored in separate attributes, and the weekly volume and sampling are also stored at this level. Inspection sampling values are done either in number of lots to be inspected, number of *wafers* per lot, or a combination of both. To ensure easier interpretation of this, the sampling percentage has been separated into two different attributes instead of just one as is the case of the old model.

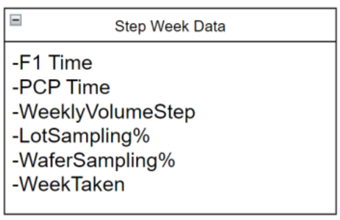


Figure 10 - Step and week Data block

One of the objectives for the new model was to increase the depth at which the model calculates operator needs. This was done by researching the way that the company sub divides operator teams in the different processing areas and ensuring that the resulting operator needs are attributed in a way that ensures recruitment and training needs are aimed in the right direction. From this analysis, the productive area structure was defined. A productive area is the dedicated location where a step is processed. These locations are grouped in 3 levels, area, sub-area and clusters, order from largest to smallest. Each step is attributed to one productive area. The structure is shown in figure 11.

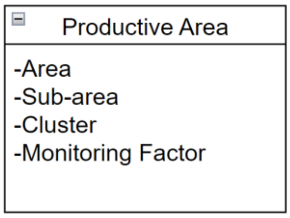


Figure 11 - Productive area block

Extra activities time, in the same way that F1 and PCP times are linked to a step and a week, need to be linked to a productive area and a week. To define an extra activity its name and unit time need to be stored and the remaining information is identified by the connection between an extra activity and the week structures, the data stored can be seen in figure 12.

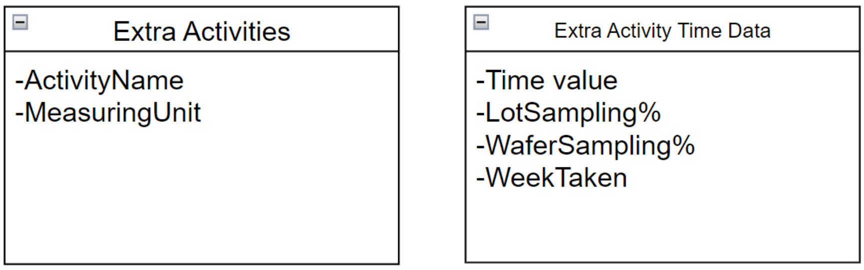


Figure 12 - Extra activities and time data blocks

The Measuring unit attribute serves to identify which conversion formula is needed to ensure proper unit dimensions are used in the calculation.

As previously mentioned, in some situations additional operators might be needed, such as to aid an AGV or other activities in the production line. Due to it being a specific allocation, the number of additional operators does not require any calculation. The structure for additional operators is connected in relation to the Productive Area structure and stores a the type of operator activity and a total quantity.

All other required information is stored in different databases, such as the case for absenteeism values. The Total UML diagram can be consulted in appendix B.

4.3 Data inputs and outputs

There are three bulk data inputs to the model. The first one is the time values that have already been described in the previous sections. For these a spreadsheet containing the flow and step name as well as F1 and PCP times should be used as a mean to insert information to the data structure. An example of the proposed spreadsheet can be consulted in appendix C.

The second needed input is the planned manufacturing volumes which is information that is updated on a weekly basis. Currently this information is also stored in spreadsheet, accessible and updated by the planning department. In order for the model to work it needs to be linked with this file. There are plans to migrate weekly plan to an online tool also, but it is not predicted to be in the near future and as so the specification assumes the current use of the volume planning model. To be able to link the headcount model to the weekly plan spreadsheet a new column needs to added that link the HCkey to the specified product reference, which can be done by taking advantage of the CapacityKey column that is already in use.

The Third data input is the historic values of the real headcount to serve as data for a comparative analysis and prediction values. These are sent monthly via e-mail to the planning department but should instead be connected directly the same way that the weekly plan values are.

The remaining data that does not need to be added in bulk, such as when adding or removing individual steps from a certain flow or sampling modifications can be done by altering the values directly through a GUI that will be presented ahead.

The process of adding data in bulk has a few caveats, as some values are directly input others are calculated or inputted later to the data structure. Therefore, some fields might not be filled the first time a flow is added. These values should be update later or as seen fit by the planning department. Default values are set by the type of product, this is the case of lot size and initial sampling percentages.

To ensure that the computation of the operator needs is not being done every time the tool is run there needs to be a defined range of time where the values are calculated, this should be 3 months and with the option of 6 months, ahead of the current week.

The calculation of the 6 month ahead period should only be used when it is requested by the planning department. When the calculations are computed, the final value of operator needs are stored, per Productive area and all the inputs that were needed to complete the calculation should also be stored at this time. For the periods outside of the 3/6 months scope input values can change accordingly but are not used for calculation purposes. This is done to reduce the computation load of the model, as some of the company's online tools are known to show a delay in calculation with data sets of similar size

The calculations could be done in a weekly basis, but taking into account the time required to interview, hire and prepare new operators it would not be efficient as it is currently impossible to adjust headcount levels in such short period of time. For constraint value updates, this should be done on a monthly basis and, as a general rule stored data should be output results and not the full input values used to compute the results.

4.4 Constraint updates

To ensure that the model correlates as closely as possible to reality, some of the assumed constraint values can be predicted or approximated with a higher level of accuracy. In this section it is explained how the these values should be treated.

4.4.1 Absenteeism and Holiday factor update

In both the case of absenteeism and holiday factors, the way of handling value prediction was done by applying the same methodology, which is explained in detail for the absenteeism factor.

For the case of absenteeism, the historical values for operator absenteeism show that the series assumes a stationary tendency, but it is also sensible to outside variables. For example, in weeks where public transport is unavailable due to strikes there is a historical increase in these values, the same happened during the covid-19 pandemic, where absenteeism values shot up rapidly. Therefore, this would indicate that a prediction algorithm that allows for rapid adaptation to real value changes should be used. For that, single exponential smoothing was the opted method[9].

As a first step, the historic values of operator absenteeism from 2017 to the 2019, shown in figure 13, were tested to verify if they in fact are stationary in nature. For this purpose the values where graphed and a linear function was used to approximate the series, and from the resulting equation it was possible to obtain the R^2 value.

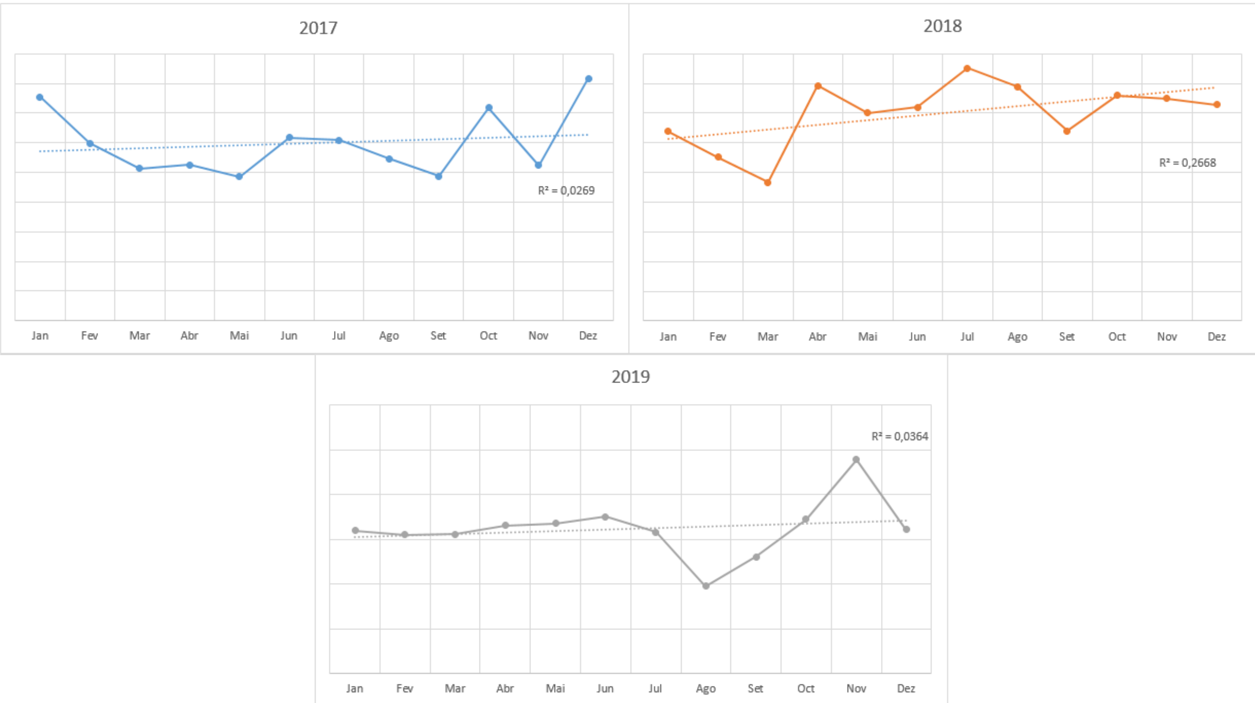


Figure 13 - Operator absenteeism percentage value for the period 2017-2019

The obtained |R| values were as follows:

Table 1 - R^2 and |R| values for 2017-2019

Year	R^2	|R|
2017	0.0269	0.1640
2018	0.2668	0.5165
2019	0.0364	0.1907

For all of the observations the |R| value, known as correlation coefficient, was lower than the referenced in the table below, for the number of observations, which is 12 for each year.

Table 2 - Confidence interval values for series tendency [19]

Nº obs	95%	99%	Nº obs	95%	99%	Nº obs	95%	99%
4	0,95	0,99	26	0,39	0,50	50	0,28	0,36
5	0,88	0,96	28	0,37	0,48	60	0,25	0,33
6	0,81	0,92	30	0,36	0,46	70	0,24	0,31
8	0,71	0,83	32	0,35	0,45	80	0,22	0,29
10	0,63	0,77	34	0,34	0,44	90	0,21	0,27
12	0,58	0,71	36	0,33	0,42	100	0,20	0,26
14	0,53	0,66	38	0,32	0,41	150	0,16	0,21
16	0,50	0,62	40	0,31	0,40	200	0,14	0,18
18	0,47	0,59	42	0,30	0,39	400	0,10	0,13
20	0,44	0,56	44	0,30	0,38	1000	0,06	0,08
22	0,42	0,54	46	0,29	0,38			
24	0,40	0,52	48	0,28	0,37			

So, after verifying that the series is stationary, it is necessary to remove the effects of seasonality from the series. For this an average of all the values referring to the same month is calculated. This value is then subtracted from the total average of all historic values and the value obtained is known as seasonality index for that month. In total, there will be 12 seasonality indexes, one for each month.

Now, to remove the seasonality effects from the series it is only necessary to subtract the respective seasonality index from all the values of the series.

The resulting series is said to be removed of seasonality. This process needs to be applied in order to obtain correct values in the next steps of the algorithm.

The final stage is to apply equation 6 to the values of the previously mentioned series.

$$\boldsymbol{Y'_{t+1} = Y'_t + \alpha \cdot (Z'_t - Y'_t)}$$

Equation 6 - Exponential smoothing equation

Where Y'_{t+1} is the predicted value Y'_t is the previous predicted value and Z'_t is the previous real value. The apostrophe is used to denote that the values are currently removed of seasonality.

As it is a recursive function the first value needs to be assumed in order to start the calculation. For the current case, this value can be the simple average of the series removed of seasonality. The α value is known as smoothing constant, a value between 0 and 1 that determines how sensible to the latest observation the resulting prediction is [4].

A conservative value should be assumed in stable situations and can be adjusted when fluctuation is expected. This factor needs to be in line with predictable disruptions, such as global or seasonal unrest and for that reason it’s modification needs to be added the planning departments workflow.

Applying the function to all series values and after adding the corresponding seasonality index a predicted value for the month after the latest observation is obtained. Every time a new value is added to the original series the process repeats, only for the current and next time periods. Historical prediction values can be saved but are not necessary to compute newer values.

For the holiday factor, the data values are in the same units and have the same update periodicity with the fluctuations that are more stable than the absenteeism so the computation can be applied in the same way.

4.4.2 Monitoring factor update

The monitoring factor is related to time attributed to an operator for machine monitoring. As was said previously the model does not take into account process time, but for monitoring activities it was identified in the old model that they have enough overall weight and need to be taken into account.

The first proposed solution was to assign to this factor a percentage value of the process time as an approximation. This can be done as process time is automatically saved for the machines that require monitoring activities, it would still be prone to significant error. Another solution was to alter the way that the times are taken to allow for the inclusion of monitoring time to PCP. This would mean retaking several new measurements, so this solution would still require the original percentage estimation. The monitoring factor would then be reduced as updated PCP times are added and when enough times had been retaken the monitoring factor would not need to be used altogether. Upon further research it was deemed not feasible to make such time measurements, as some of the process times are over 8 hours long and would require full time presence of an IE element to perform a single measurement.

The compromise solution that was settled was to sub divide the percentage value by the different productive areas. This was since the productive areas (PA) are organized by machines of the same type, and consequentially the amount of monitoring is similar for similar processes.

4.4.3 Engineering factor update

The engineering factor is a value that is attributed to operator activities that help with engineering processes. The amount of help needed is proportional to the total wafer volume for any given week. The larger this value the larger the percentage value of the engineering factor. Currently it is simply a step-based function. 5000 *wafers* correspond to 5%, 10.000 *wafers* correspond to 10% and anything above is given 15%. This proportionality should be adjusted to a linear relation instead of a step function, as otherwise this can result in a big percentage jump with just the increase of one wafer.

4.5 User Interface definition

After defining, the data structure for the tool it is needed to thoroughly comprehend who are going to be the main users of the tool and what are the needs that should be met for each of the users.

The main user of the tool, in terms of data updates are the planning (PL), industrial engineering (IE) and production engineering (PE) departments. Other departments that also take advantage of the model are the human resources department (HR), for recruitment planning, and the financial department (F) to estimate productions cost for product price negotiation, which include headcount costs as a factor.

In order to avoid the need for the required weekly meeting, the tool should have different windows accessible individually by each of the departments. This means that a new workflow can be defined where each of the users individually can make requests and alterations to their part of the model instead of having to do so in the weekly meeting.

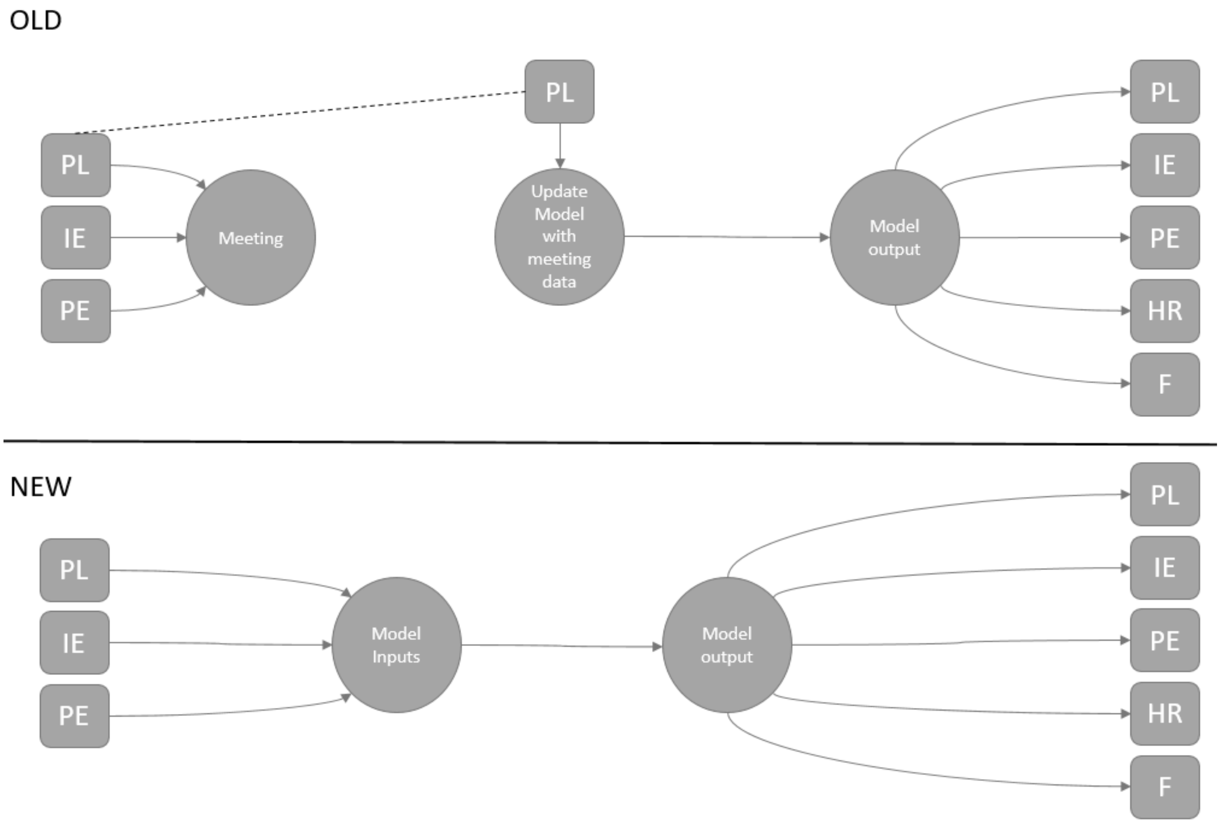


Figure 14 - Old to new workflow

A PE user should be able to select a flow and view all the steps that comprise it and respective time values and information, for a set number of weeks in the future. If the user determines that a certain step should be measured, whether for the first time or to be updated, he should select the respective step. After the user selects all the steps that require measuring, they are submitted and should appear as awaiting measurement. The PE user should also be able to attribute a priority to a time measurement on a 1 to 4 scale, such as the one that is done to individual lots in the company MES.

For the IE user, a window showing all of the requests should appear and be able to be filtered by flow or by production area. The IE user should then select the steps that are going to be measured and download a preformatted spreadsheet with the steps and blank spaces to fill with time values. After all steps are measured, the user should submit it to the tool. The way of doing this is through a spreadsheet, which is stored and then waits for confirmation from the planning department. With extra activities measurement the same methodology is followed, the only exception being that the type of unit used should also be inputted.

For the PL user, the same capabilities of the PE window should be available. It should exist a window that shows all the spreadsheets submitted by the IE department and that are waiting for confirmation. If the values in the sheet are correct the PL user should select it and click a submit button that loads the time information into the database. If the times are incorrect, the user should identify that there is an error. This action should send back the spreadsheet to the IE department window with comments for the IE department to analyze, update and re-submit the spreadsheet.

Other users should have access to the windows containing all the reporting data, both the raw data values and to the visual reporting and simulations. They should not however be able to do permanent changes to the values, as this is a responsibility of other departments.

4.6 Graphical User Interface

The tool should be simple to understand and utilize. For that reason mock-ups of the intended design were made to better convey how the application should look and function. The mock-ups were developed on the diagrams.net open platform, which is an open source technology stack for building diagramming applications [6].

For most cases, these were based on already existing web-applications of the company, as this would aid the overall in the future tool integration phase.

In Figure 15, the time request window for the PE and PL department is presented, on the top left the filtering options are detailed being Technology type, customer and flow. These are selected in a sequential manner from left to right. The values highlighted in red represent process times that have never been added to the model, after the time value is added for the first time it is then changed to white. In the request column, requested times should be picked by clicking on the respective step check box. The user may also set, on a 1 to 4 scale, the priority it sees fit, the visual representation of this is done by a color gradient from red to green.

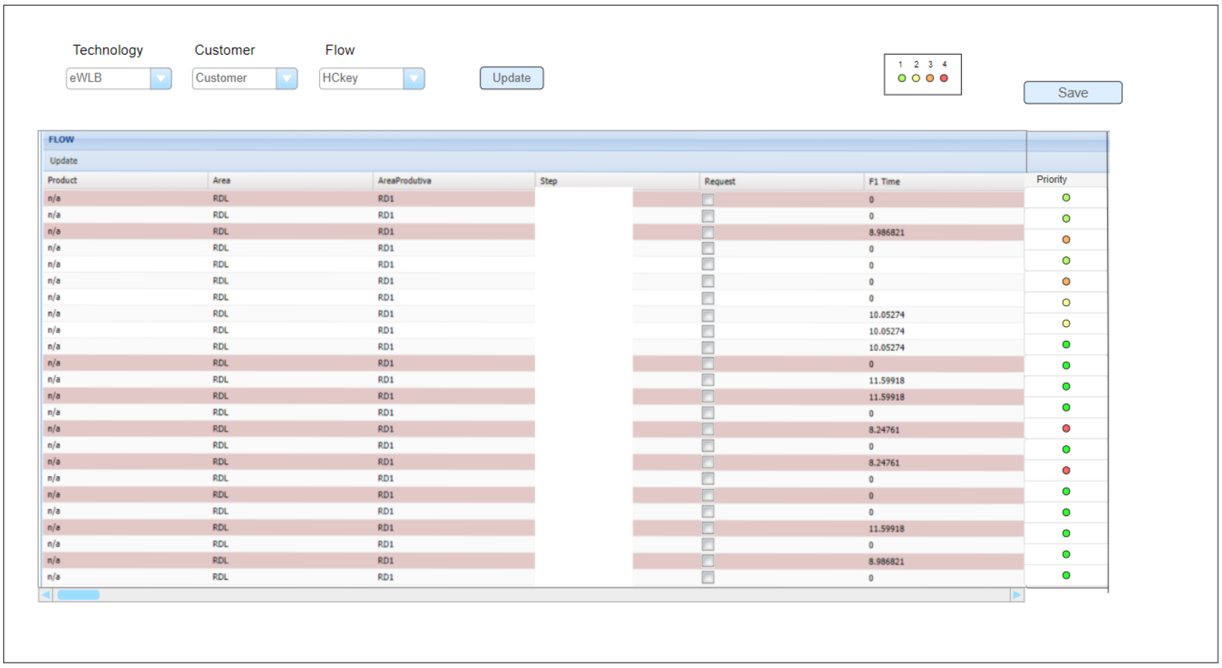


Figure 15 - PL and PE Time request Window Mock-up

In Figure 16 the IE window is shown, the structure is similar to the PL and PE window but the priorities are not editable. The measure column is used to identify the steps that are going to appear in the pre-formatted spreadsheet to be used in time collection.

For the preformatted spreadsheet, an example is shown in appendix C. The configuration was based on other time collection templates already in use by the IE department.

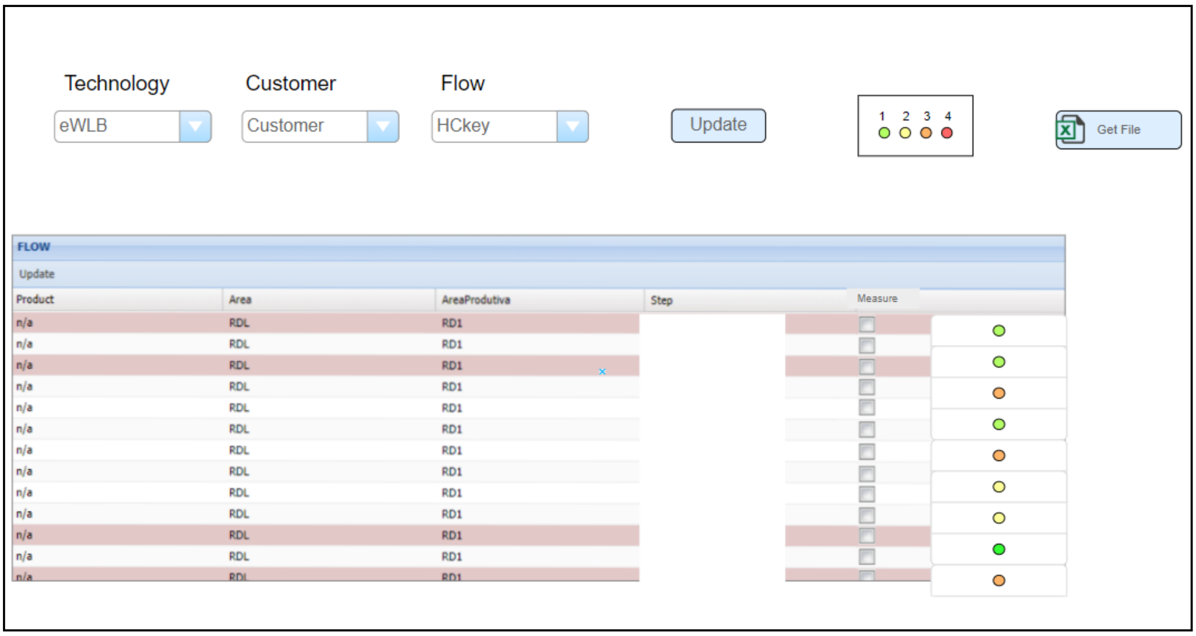


Figure 16 - IE window mock-up

In Figure 17, it is shown the PL window for times waiting approval. In this window all of the time measurements files submitted by the IE department are shown in order from the oldest on top, to the newest on the bottom. Opening the each tab, the spreasheet file is accessible and any comments that refer to the whole measurement process are shown. After the PL user analyses the file he can select whether it is accepted or not. If it is accepted, the values are automatically loaded or updated in the database. If not, the PL user can comment on the reason for not being accepted and send back the file to the IE department for alterations.

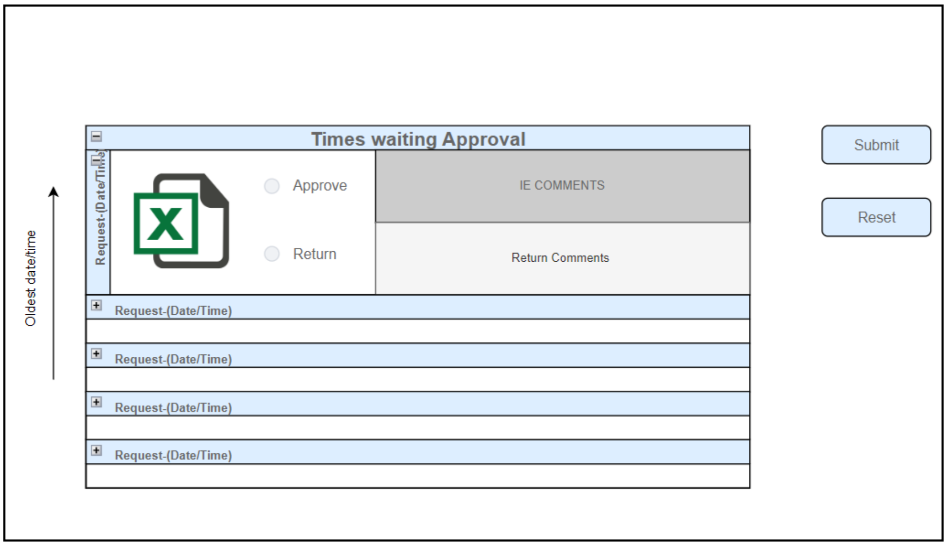


Figure 17 - PL Times waiting approval window

In Figure 18, it is shown the IE returned times window. This window shows the user all files that were not accepted by the PL department. The IE user can then get access to the file and respective comments and make alterations. The user can then submit the file and it will show again on the PL Times waiting approval window.

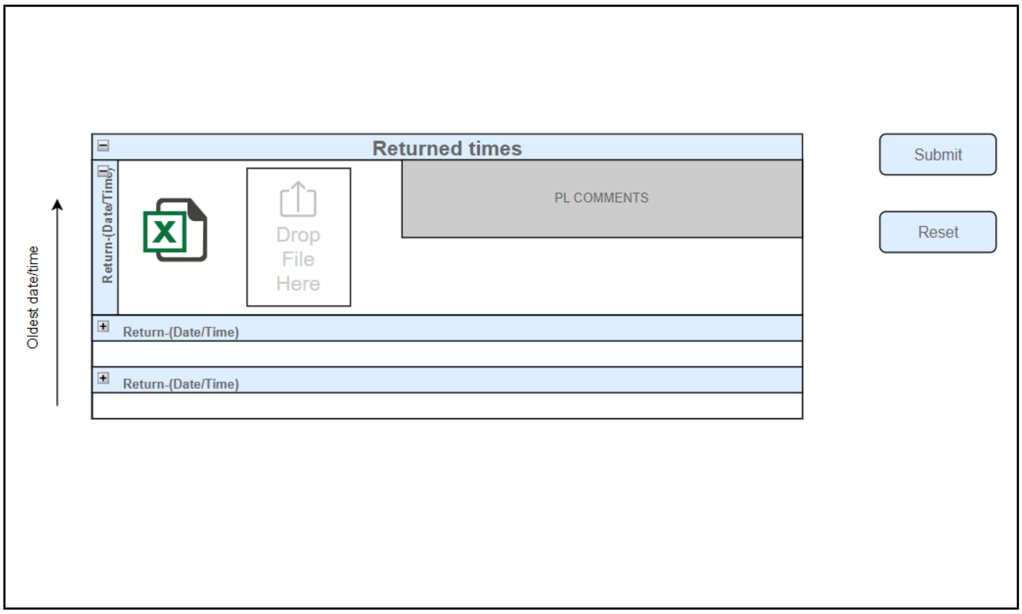


Figure 18 - IE Returned times window

5 Reporting solutions and expected results

In this chapter, all of the reporting solutions are shown as well as the research that served as base for the different types of reports. In addition, it is also made a summary of what are the expected benefits gained from the future implementation of the tool in the company.

5.1 Reporting

In this section, the reporting solutions proposed for the new tool are presented. The reports were categorized as either graphical reports, if they displayed data by using charts or graphs, or tabular reports if they consist of primarily of data values.

5.1.1 Graphical reports

The first and main visual output of the model is the stacked bar chart that displays the weekly needs for all areas, based on the yamazumi charts method. The similarities with this method and the intended report are mainly related to the visual output. The mock-up for the window can be found in appendix A.

As was said before the majority of operator time is considered to be non-value added so the time collecting logic of the yamazumi method would not be used to great effect. However, by using the stacked bars to represent the area operator needs it is possible to see which areas are the most demanding in terms of headcount and how different product types affect the models output. This coupled with the forecasted demand can be used to predict and be prepared in the event of a large increase or decrease of demand in a given product type. The same can be done with the constraint values.

The graph is displayed on the left side of the window for the weeks selected by the user. In addition to the stacked bars a line chart should show the demand volumes for the requested weeks, either total volume or by type of product. This window also serves to update constraint values and simulate alterations. The current constraints are displayed on the right side.

For operator team organization it was also identified that metrology needs per area should have a toggle option, this is due to the fact that these operators are required to have proper certification to be able to execute these types of steps. An example of the output graph is shown in figure 19.

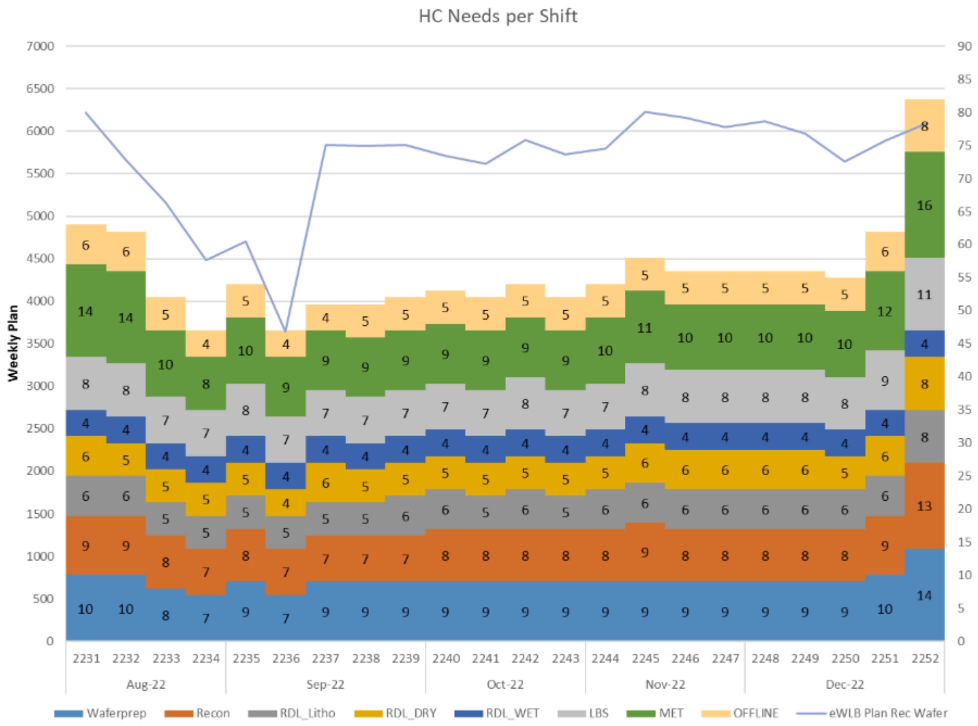


Figure 19 – Expected yamazumi output graph example

In addition, it was asked that the tool also have a way to display total calculated values and compare them to the real number of operators of that same period. To do this, a double line graph was selected displaying the weekly evolution of both values. To aid interpretation the average delta value between real and calculated values for the last quarter and semester are also displayed, to serve as quantitative KPI for HR. The mock-up for this window is shown in figure 20.

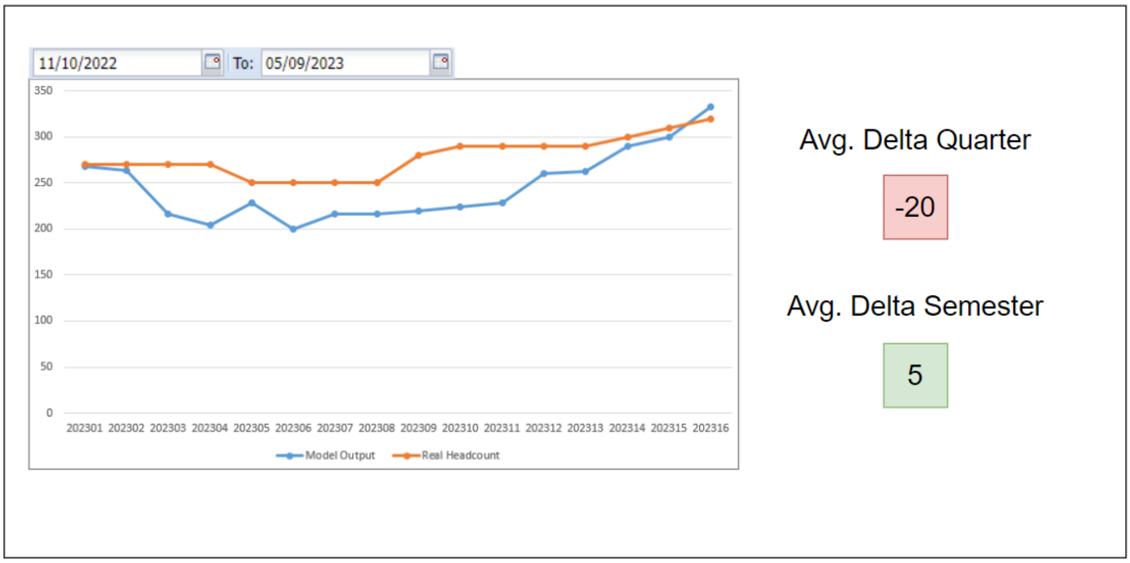


Figure 20 - Historic Headcount window

As both higher or lower values correspond to unnecessary costs, as was mentioned in section 2.4, the display boxes should be highlighted with a different color depending on how far the real value strays from the expected one. The selected colors were green when the value is zero, representing ideal operator number. The highlight should turn to red in a gradient manner the larger the distance from the ideal scenario.

5.1.2 Tabular reports

Even though visual solutions are preferable and easier to understand than the raw results on a spreadsheet, it was identified that there should also be a way to have access to the output information in a tabular form. This was the case for the data necessary to ensure that the calculations presented in section 4.4.1 were feasible. The values were obtained by request to the HR department, which provided a tabular report with the needed data.

Following the same train of thought, it is possible that in the future other departments will have the need to have an easy way to access the values calculated by the model, for their own work.

The mock-up for the tabular report window is shown in figure 21 and is described as follows.

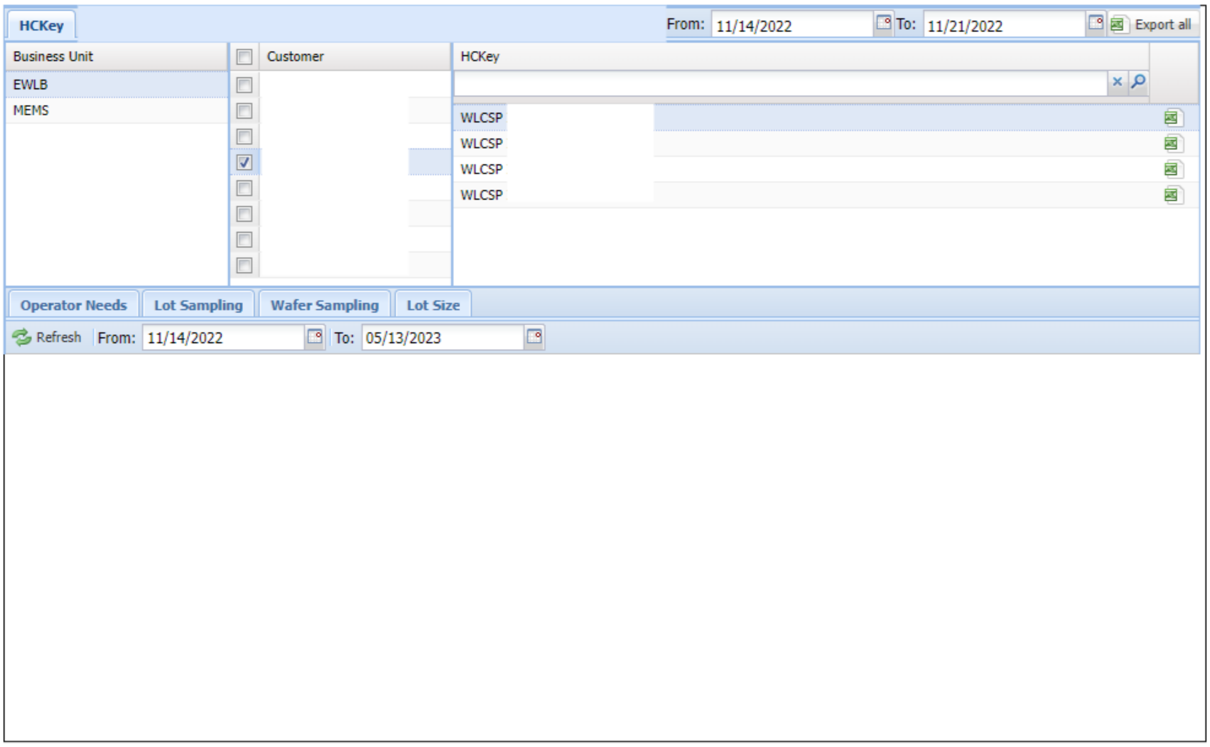


Figure 21 – Main tabular report window

These tabular reports should filter which data the user wants to have displayed. The filtering options chosen were business unit, the corresponding customer and finally the HCkey. These options are selected sequentially in the same order presented. At the bottom of the window different sub-panels should contain a tabular report of the values for the weeks selected. Examples are shown for the operator needs, sampling percentages and lot sizes, but more can be added as when the need arises. The option of exporting all the data to spreadsheet file should be present.

Another tabular form requested was one that would serve de financial department to attribute a cost value to each process step, as this is one of many taken into account for price negotiation with the costumer. As shown in figure 22, the report consists of a list filtered in the same way sequential manner as the main tabular report window, which for each step attributes a monetary value per week.

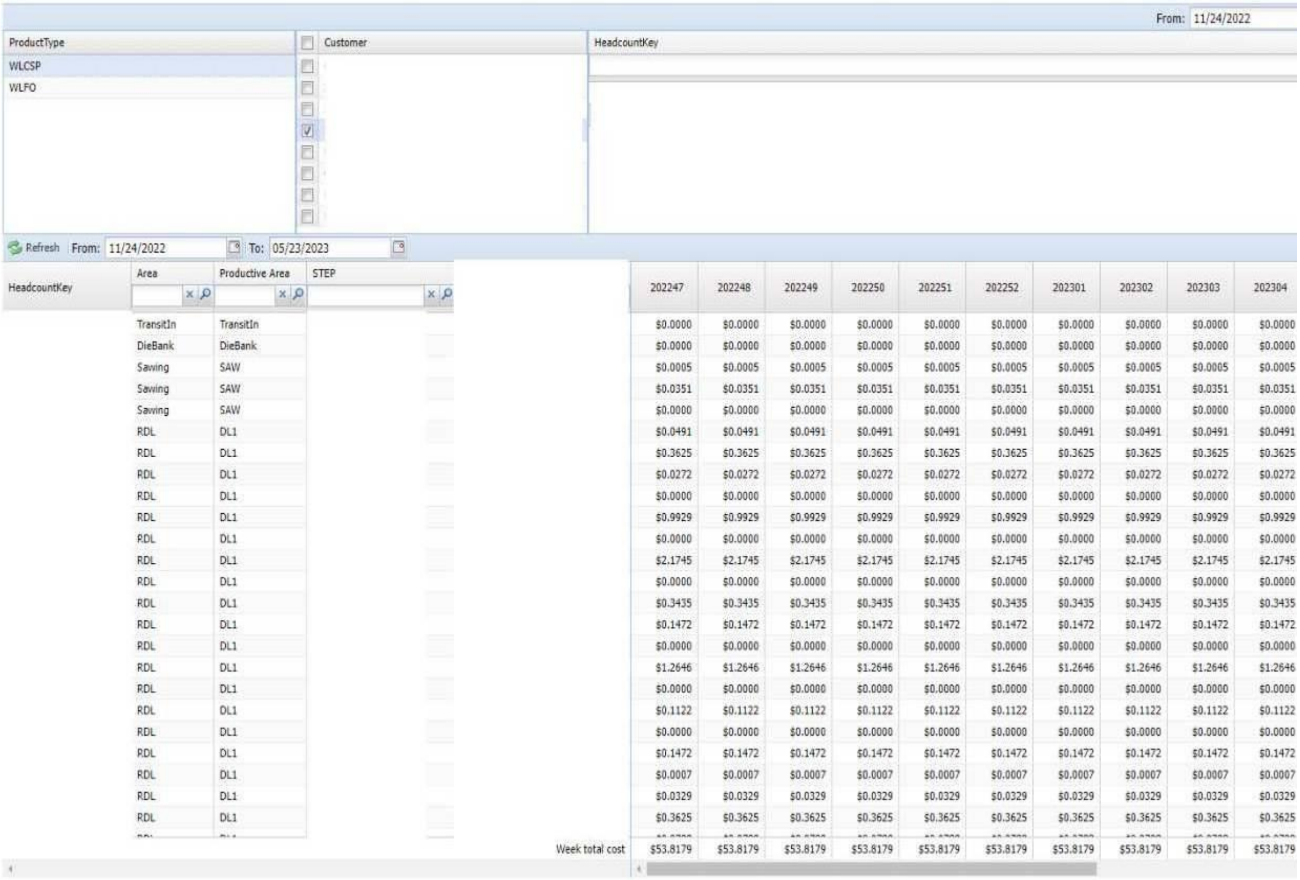


Figure 22 – Financial report window

This was a process that was being done manually by using a spreadsheet to divide the hourly rate that an operator is paid by the step time value. The issue with calculating the values this way is that the step times used by the financial department often were outdated from the ones that the planning department had. Therefore, as step times in the new tool are stored in only one database, this can be calculated automatically and displayed to the user.

5.2 Expected savings

In this section, a pondered estimation is made of what the major benefits attained are from the use of both the new tool and the renewed workflow. These include estimations of time savings, step-time update frequency and constraint update effects.

5.2.1 Time Savings

In order to estimate how much impact the future implementation is going to have in terms of time savings, it is necessary to compare it with the amount of time currently spent by each department to keep the model updated.

In terms of weekly time for the PL, IE and PE departments, a total of 3 hours is spent in meetings debating new product addition and step-time measurements. Furthermore, the PL department estimates that an additional hour is needed on average to insert, remove and update information in the model's spreadsheet. Yearly across all departments this amounts to upwards of 208 hours spent on meetings and model upkeep. By implementing the proposed solution, that makes it so meetings are not need, an estimated 156 hours are gained by the company. The saved time can then be allocated to ensure that other department activities can be prioritized, which will result in an indirect increase to the value of both the department's time and an increased rate of process improvement.

Another way that the new tool will save time is by allowing for quicker analysis of different products impact on headcount, which is currently a task that currently amounts for an average of 15 minutes per request, due to the need of manually coping the values from the spreadsheet in order to create graphical reports. Last year, there were 60 requests of this kind amounting for around 15 hours dedicated to this kind of test. The new tool should be able to reduce this value closer to 5 minutes, as it will automatically filter the required information as well as directly outputting the reports needed. This reduction value is estimated based on similar kind of requests made to the capacity-planning tool and represents a drop to third of the current time spent on this requests.

The major benefit estimated of these time savings is not the reduced cost directly from the department's members' salaries, but in the increased time available for these members to contribute more in their respective areas of work. The PL element would now have more time to better align production plans and equipment capacity constraints, the PE member could optimize the weekly distribution of lots to the production line and the IE element could dedicate more time to process improvement which in turn results in added value to the final product.

5.2.2 Step-time update

As with any kind of algorithm that has a large data set as a central part of it's computation, the output result is only as good as the data that is input to it. An expected benefit of defining priorities to the step-time collection process is, ensuring that the values that are the base of the model's output are as closer to the truth. Furthermore, by signaling steps that have not been updated for a long period of time, it is ensured that any changes to the production process that affect operator time is correctly accounted for.

In the old model, some step-times were not measured, but instead copied from similar product times. Although some step times might be similar across different products, this practice still introduces uncertainty to the model. By streamlining the process of adding and updating step times by allowing for bulk alterations using a spreadsheet and setting priorities for time measurements, there will be less resistance to correctly update values.

5.2.3 Constraint updates

An analysis was made to compare how effective the prediction of the absenteeism value was. To do this, the relative error with, respect to the real absenteeism value, was calculated for the predicted values and compared to the one obtained with the fixed absenteeism factor value.

The number of times that each of these had the lowest error was counted for the total number of real absenteeism values available. This procedure was repeated for increasing values of α in 0.05 size increments, to also serve as a measure for the method's sensitivity, and were graphed as shown in figure 23.

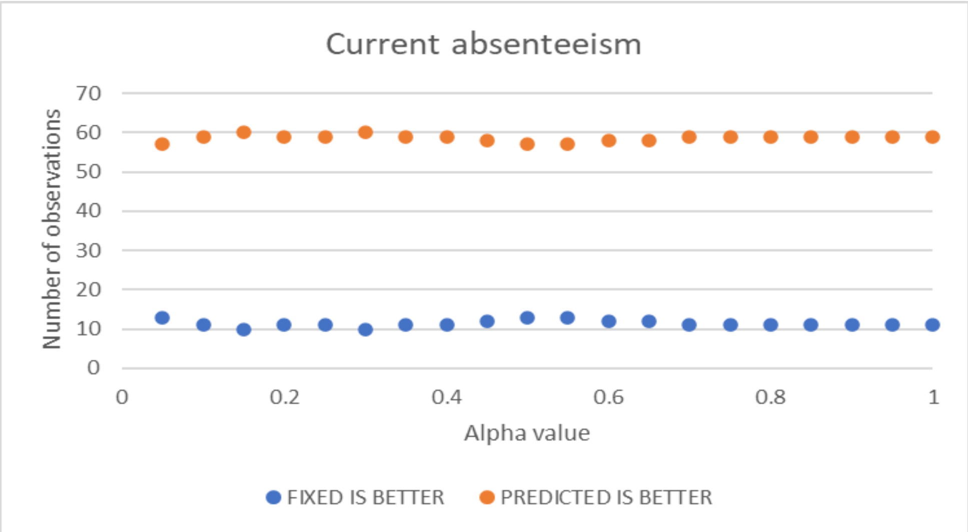


Figure 23 – Current absenteeism error comparison

The first conclusion made from observing the output graph was that, the number of times that the error value was lower in the case of using the exponential smoothing was higher. At first glance this would mean that the prediction model is working as intended, but another observation made was that the α value did not seem to have any significant influence. A possible explanation for this could be that value currently used by the company much higher than the real one.

To understand if this was in fact the case, a new graph was made, this time by using the average value from the real observations as the estimated value. The resulting graph is shown in picture 24.

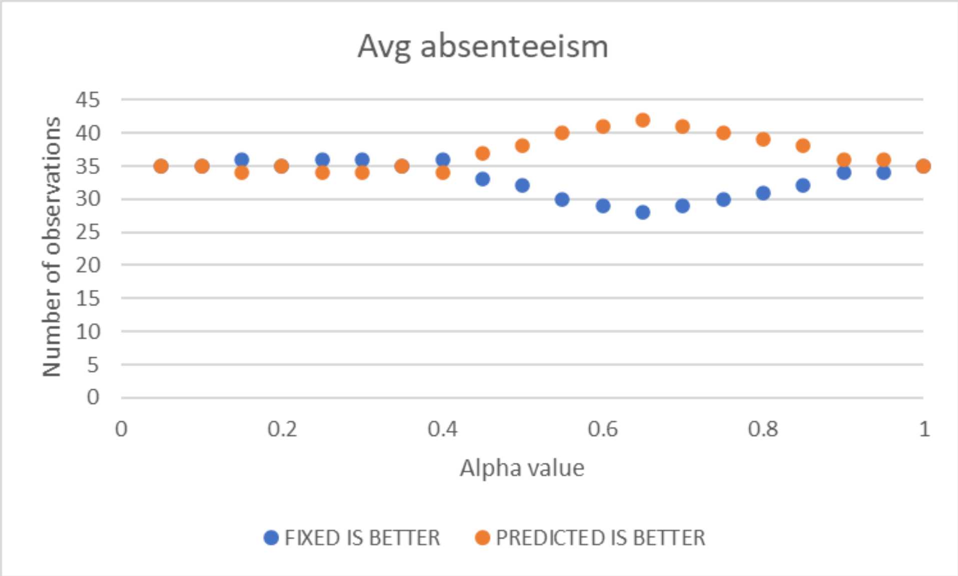


Figure 24 – Average real absenteeism error comparison

This time it is possible to confirm that the number of times that each variable has a lower error value is much similar. However, as was expected, by increasing the value of α to a value closer to the 0.5-0.8 range the number of observations where the error was smaller for the predicted model increased. It results that, by increasing the value of α the weight of the last real observed values is increased. But it is also possible to confirm that an excessively high α value decreases the method's effectiveness.

It is important to mention that, even though it is possible to improve the models result by directly adjusting the absenteeism factor, as was evidenced by the results previously discussed, the possibility for a bad estimation is higher than by making estimations for the which α value is best to use. The exponential smoothing method adds a dampening effect to the predicted value even for extreme values of α, which in the worst case scenario still perform as good as the best fixed estimation.

6 Conclusions and future work

6.1 Main Conclusions

The main objective of the project was accomplished, with the resulting specification still open for further improvement and adaptations when the implementation and integration phase begins. The developed work will allow for reduced waste time related to headcount planning activities of ATEP, as stated in the previous section. Several reference sources were used to ensure that the needs of the tool were simple to understand, and that all needed information was compiled. All involved departments were contacted, and gave their opinion on the best way to improve on the current model.

The way that the data is stored was redefined, by means of a UML class diagram, to minimize the computing requirements and to avoid recurrent application crashes that resulted from using spreadsheets as data storage. Moreover, a simpler analysis of how different variables impact headcount values was made possible, which previously would mean changing several values individually in order to obtain them. This coupled with the new way of adding product flows, by uploading of a complete spreadsheet, makes it so new products can be added in bulk, reducing the propensity for error.

The scope at which the tool now is able to calculate operator needs was also increased with the changes made to the stored data. This analysis is now made at a cluster level, facilitating the way that recruitment and training strategies should be aimed. Clusters with more operator needs can now be prioritized in terms of operator qualification, making sure that there are no delays resulting from lack of qualified labor.

The modifications made to the available time constraints, based on prediction techniques, namely the exponential smoothing method, allows a closer approximation to the real needs. This will directly result in fewer cases of overstaffing and cost savings by maintaining operator headcount closer to required levels.

For the departments that used the tool's output for other work activities, it was made easier to obtain needed data, ensuring that the values attained are up to date. The graphical reporting solutions made sharing of the obtained results more perceptible and the addition of a simpler forecasting GUI makes analyzing headcount variables easier. The groundwork was also laid for future reporting solution to be added as part of the existing window based structure.

6.2 Future work opportunities

Some future work opportunities were identified throughout the development of the project as they did not relate to the current solution objectives.

The main future work relates to preparing the model to be used with new technologies types being produced by ATEP, such as MEMS. This would mean adding the new product flows to the model and understanding whether there are any significant process differences that would require adaptation to the way that the model is updated by each department.

Another opportunity identified, was the possibility of replicating the same step time based model to the technicians headcount. This is currently being done through an MMR model, which means that the same type of conversion as was done with operator headcount could possibly be applied. To this, the added fact that technicians are mainly responsible for maintenance tasks and that these task are already being measured in terms of duration means that there is enough ground work laid to justify possible integration with the headcount tool.

Some of the possibilities were also related with other projects currently in development within the planning department. One of the problems that is still trying to be implemented is the handling of rework and error correcting activities and how to correctly estimate its impact in equipment availability. This type of corrections are not usually predictable which makes it difficult to estimate with a small margin of error. This problem when solved and implemented can also be used to better estimate the impact of these activities in operator headcount.

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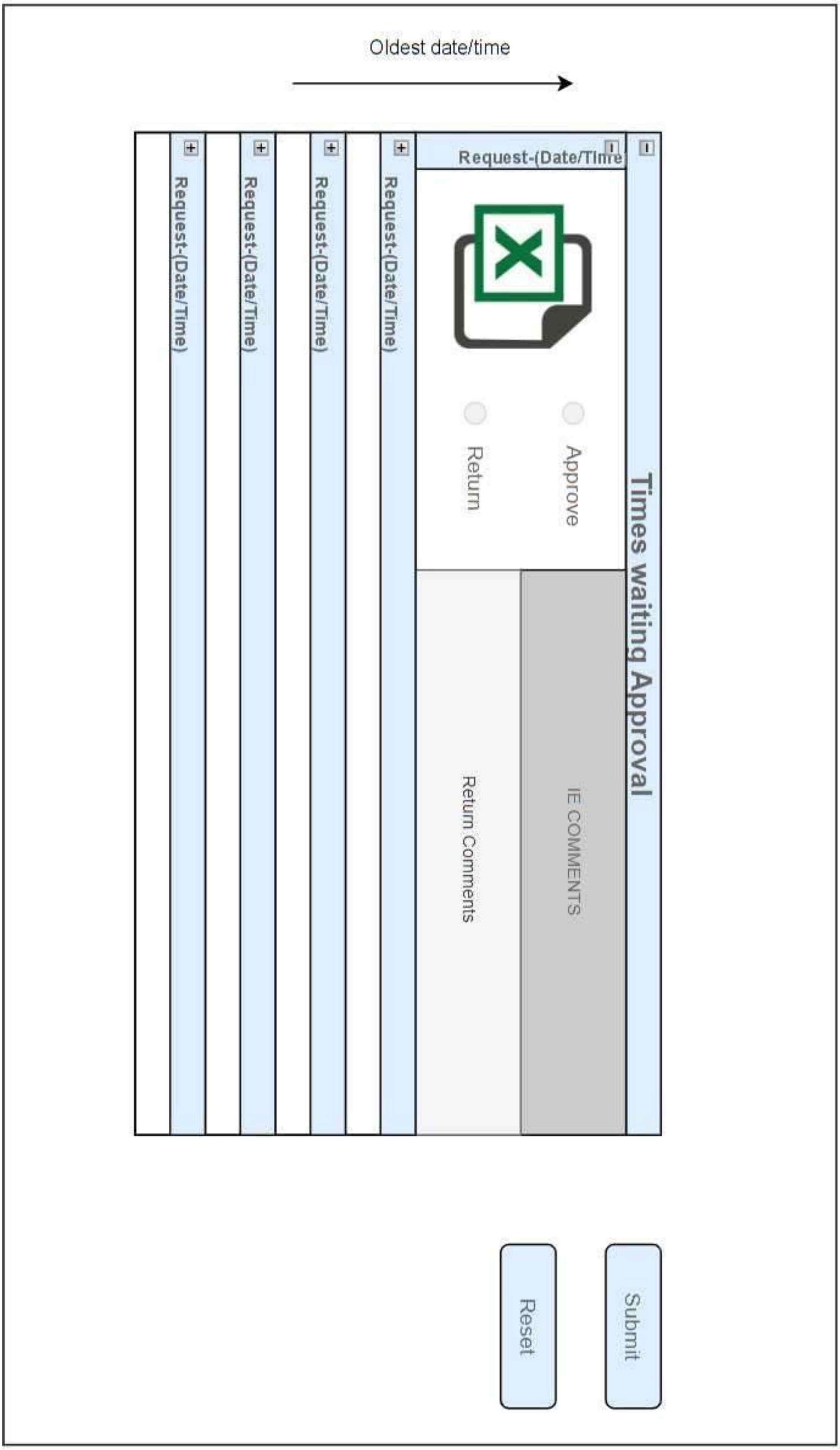
APPENDIX A: Tool design mock-up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Times waiting Approval
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Approve
Return
IE COMMENTS
Return Comments
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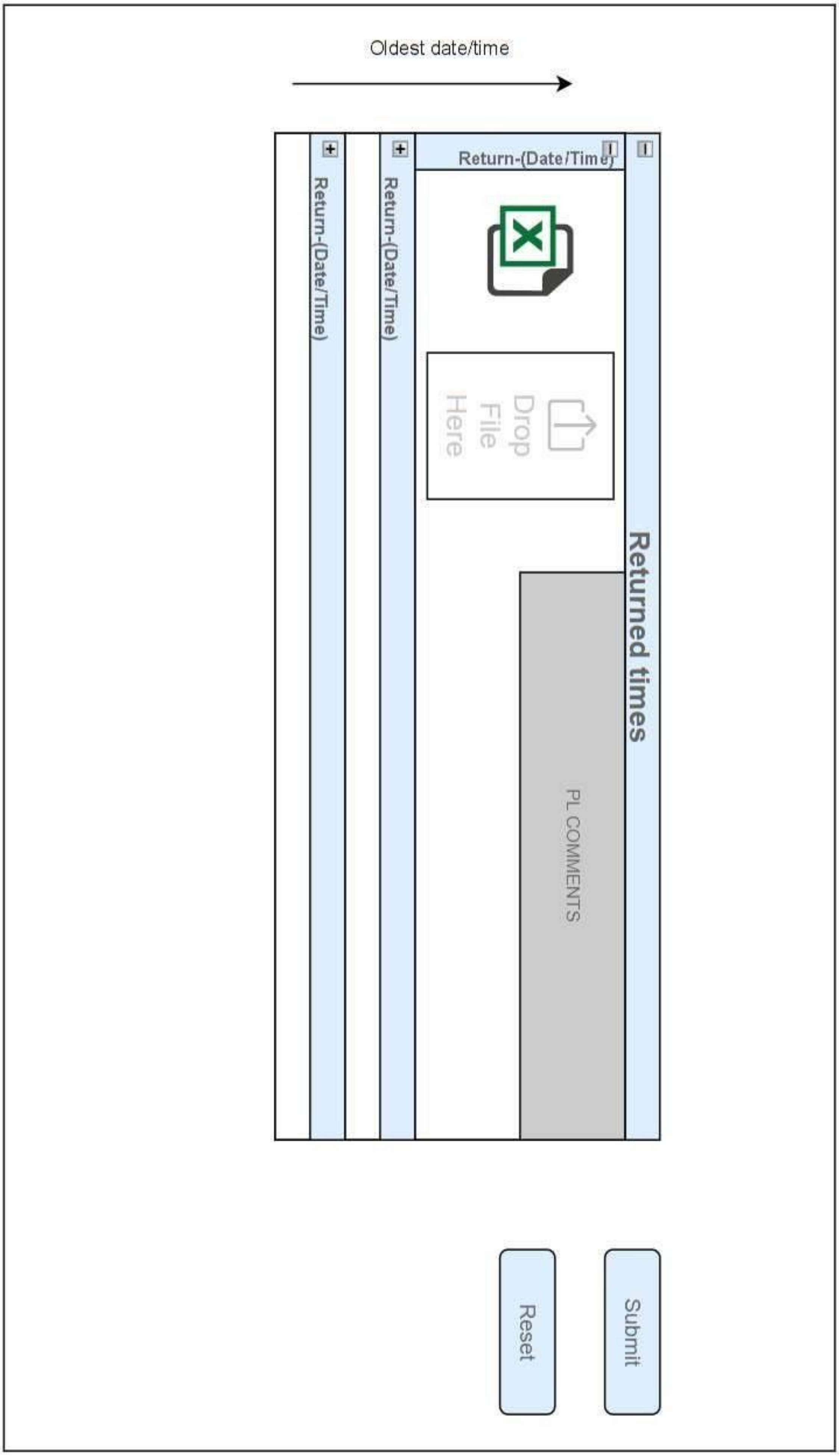
Submit
Reset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Returned times
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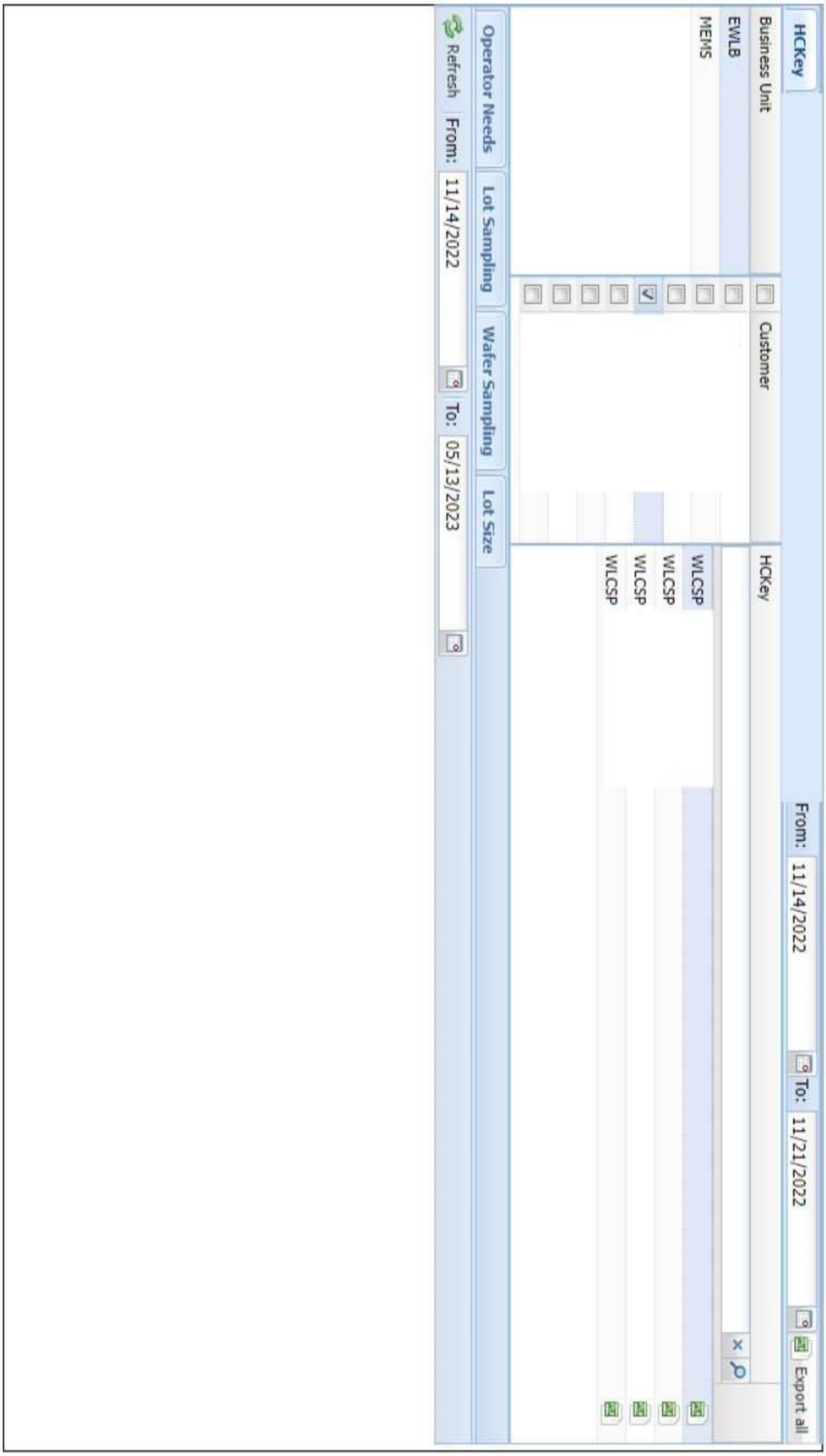
Return-(Date/Time)
Return-(Date/Time)
Submit
Reset


Technology
eWLB
Customer
Customer
Flow
HCkey
Update
1 2 3 4
Get File
FLOW
Update
Product
Area
AreaProdutiva
Step
Measure


11/10/2022
To: 05/09/2023
Volume Type
Total
Include Metro
HC Needs per Shift
Weekly Plan
Employees per Shift
Waferprep
Recon
RDL_Litho
RDL_DRY
RDL_WET
LBS
MET
OFFLINE
eWLB Plan Rec Wafer
Aug-22
Sep-22
Oct-22
Nov-22
Dec-22
Area
WaferPrep
Update
Reset
Absenteeism
Breaks
Recovery
Eng Support
Holiday
5%
15%
9%
5%
5%
Set Values


HCKey
Business Unit
EWLB
MEMS
Customer
HCKey
WLCSP
WLCSP
WLCSP
WLCSP
From: 11/14/2022
To: 11/21/2022
Export all
Operator Needs
Lot Sampling
Wafer Sampling
Lot Size
Refresh
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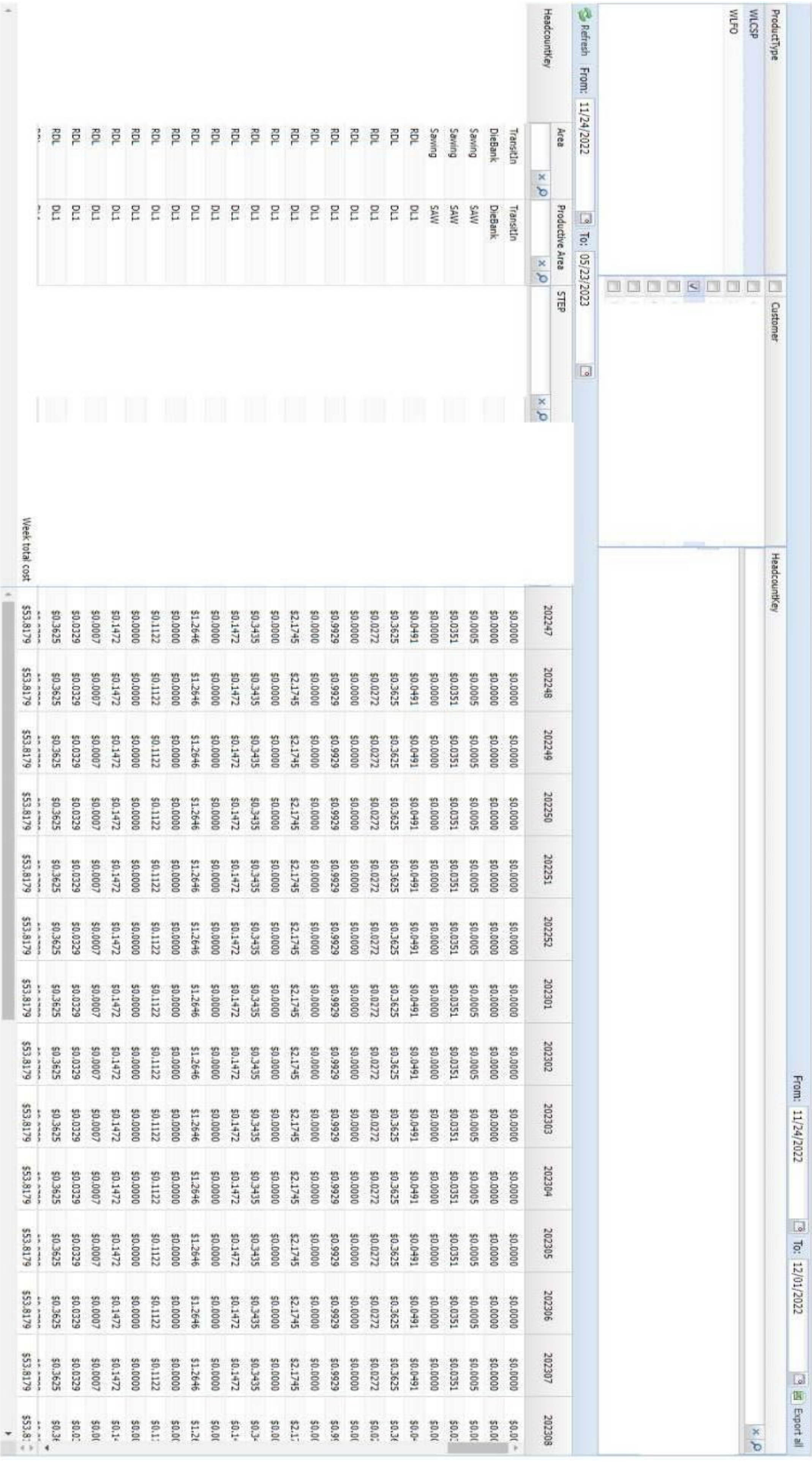
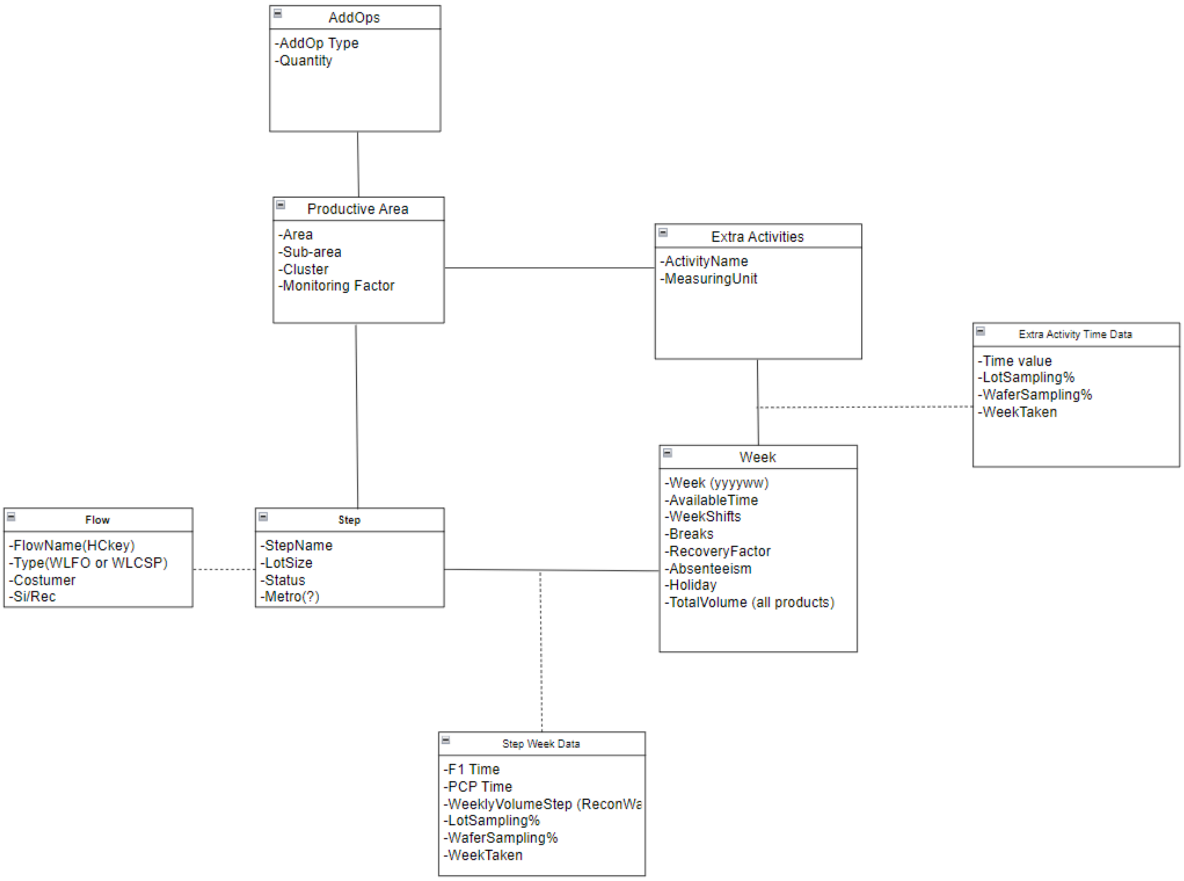
To: 05/13/2023



HeadcountKey	Area	Productive Area	STEP	202247	202248	202249	202250	202251	202252	202301	202302	202303	202304	202305	202306	202307	202308
	TransitIn	TransitIn		$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0
	DieBank	DieBank		$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0
	Saving	SAW		$0.0005	$0.0005	$0.0005	$0.0005	$0.0005	$0.0005	$0.0005	$0.0005	$0.0005	$0.0005	$0.0005	$0.0005	$0.0005	$0.0
	Saving	SAW		$0.0351	$0.0351	$0.0351	$0.0351	$0.0351	$0.0351	$0.0351	$0.0351	$0.0351	$0.0351	$0.0351	$0.0351	$0.0351	$0.0
	Saving	SAW		$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0
	RDL	DL1		$0.0491	$0.0491	$0.0491	$0.0491	$0.0491	$0.0491	$0.0491	$0.0491	$0.0491	$0.0491	$0.0491	$0.0491	$0.0491	$0.0
	RDL	DL1		$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3
	RDL	DL1		$0.0272	$0.0272	$0.0272	$0.0272	$0.0272	$0.0272	$0.0272	$0.0272	$0.0272	$0.0272	$0.0272	$0.0272	$0.0272	$0.0
	RDL	DL1		$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0
	RDL	DL1		$0.9929	$0.9929	$0.9929	$0.9929	$0.9929	$0.9929	$0.9929	$0.9929	$0.9929	$0.9929	$0.9929	$0.9929	$0.9929	$0.9
	RDL	DL1		$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0
	RDL	DL1		$2.1745	$2.1745	$2.1745	$2.1745	$2.1745	$2.1745	$2.1745	$2.1745	$2.1745	$2.1745	$2.1745	$2.1745	$2.1745	$2.1
	RDL	DL1		$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0
	RDL	DL1		$0.3435	$0.3435	$0.3435	$0.3435	$0.3435	$0.3435	$0.3435	$0.3435	$0.3435	$0.3435	$0.3435	$0.3435	$0.3435	$0.3
	RDL	DL1		$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1
	RDL	DL1		$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0
	RDL	DL1		$1.2646	$1.2646	$1.2646	$1.2646	$1.2646	$1.2646	$1.2646	$1.2646	$1.2646	$1.2646	$1.2646	$1.2646	$1.2646	$1.2
	RDL	DL1		$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0
	RDL	DL1		$0.1122	$0.1122	$0.1122	$0.1122	$0.1122	$0.1122	$0.1122	$0.1122	$0.1122	$0.1122	$0.1122	$0.1122	$0.1122	$0.1
	RDL	DL1		$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0
	RDL	DL1		$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1472	$0.1
	RDL	DL1		$0.0007	$0.0007	$0.0007	$0.0007	$0.0007	$0.0007	$0.0007	$0.0007	$0.0007	$0.0007	$0.0007	$0.0007	$0.0007	$0.0
	RDL	DL1		$0.0329	$0.0329	$0.0329	$0.0329	$0.0329	$0.0329	$0.0329	$0.0329	$0.0329	$0.0329	$0.0329	$0.0329	$0.0329	$0.0
	RDL	DL1		$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3625	$0.3
Week total cost				$53.8179	$53.8179	$53.8179	$53.8179	$53.8179	$53.8179	$53.8179	$53.8179	$53.8179	$53.8179	$53.8179	$53.8179	$53.8179	$53.8


Technology
eWLB
Customer
Customer
Flow
HCkey
Update
1 2 3 4
Save
FLOW
Update
Product
Area
AreaProdutiva
Step
Request
F1 Time
Priority

APPENDIX B: Complete UML Diagram



APPENDIX C: Preformatted Spreadsheet template

Time Collection

Date		Area Produtiva		Flow	

	F1	PCP	Notes
Step 1			
Step 2			
Step 3			
Step 4			
Step 5			
Step 6			
Step 7			
Step 8			
Step 9			
Step 10			
Step 11			
Step 12			
Step 13			

Total		