A simulation study of capacity utilization in a third-party logistics provider warehouse

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ABSTRACT

A simulation study of capacity utilization in a third-party logistics provider warehouse

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Nowadays companies focus more on their core business operations and subcontract third parties to perform services that were traditionally performed in-house. A third-party logistics provider (3PL) is an organization used to outsource elements of the supply chain like transportation and warehousing services. In 2019 this industry contributed about 90 billion CAD to the total Canadian GDP.

One of the biggest constraints in warehousing, is the effective management of warehouse capacity. Warehouses are physically limited by their layout, number of pallet positions, number of dock doors, size of the storage locations, size of the aisles, among others. Additional challenges may arise due to the seasonality of storage requirements. 3PL providers offering warehousing services are thus interested in determining at which levels of used capacity a warehouse is more profitable. This information can then be used to develop an order-accepting strategy for the company to be used during low and high seasons.

The main contribution of this thesis is to develop a simulation tool that provides a good starting point to answer these questions. In particular, the thesis focuses on a case study involving the operations of one particular 3PL warehouse with a major customer who moves only full pallets. This 3PL handles temperature sensitive products using a turret truck in a narrow aisle work environment.

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Chapter 1. Introduction

In 2007, the logistics service industry was expected to increase by 40% between the years 2007 and 2015, for a yearly contribution of 56 billion Canadian dollars to the total Canadian GDP. In 2019, the transportation and warehousing industry contributed around 90 billion CAD to the total Canadian GDP. This is a sign of good economic health for this industry in Canada. Sectors such as transportation (tuck, rail, pipeline, air and marine), 3-4-5PL support activities, warehousing, storage, and postal services are part of the logistics service industry.

VersaCold Logistics Services offers to the Canadian market an integrated logistics service. The company operates the largest temperature sensitive logistics network in Canada, with around 30 temperature controlled warehouses and distribution centers, and a fleet of trucks providing local, regional, national and international transportation across Canada and the United States. This third party logistic (3PL) company offers outsourcing services such as warehouse management and transportation. VersaCold provides additional services including: co-manufacturing, co-packing/labelling, billing, tracking, and supply chain management (Versacold, 2019).

One of the biggest constraints in warehousing, for Versacold in particular, is the effective management of warehouse capacity. Warehouses are physical limited by their layout, number of pallet positions, number of dock doors, size of the storage locations, size of the aisles, among others. Another challenge for Versacold is that its clients are all in the food business, which means that storage requirements are seasonal and temperature sensitive. The raw materials are affected by harvest seasons and the demand of final products is also driven by the time of the year. For example, ice cream demand increases during the Summer and decreases during Fall and Winter. This seasonality aspect brings a big challenge to VersaCold. During the high season period, warehouses runs a full capacity, but during the low season period the warehouse may run with a lot of empty spaces. This business dynamic is a critical challenge to the company and thus, motivates the present study. The company wants to determine at which levels of used capacity the warehouse is more profitable. This information can then be used to develop an order-accepting strategy for the company to be used during low and high seasons.

The main contribution of this thesis is to develop advanced analytical tools that provide a good starting point to answer these questions. In particular, the thesis focuses on a case study involving the operations of one particular 3PL warehouse with a major customer who moves only full pallets. Different data collection techniques are used to determine the time of the operations. The speed of the machines is calculated using a stopwatch and an analysis of the body movements is done using the Maynard Operation Sequence Technique (MOST). All the collected data is studied and used as input information in the simulation model, which is built using one year of data for a customer in a 100% full pallet pick environment. The proposed Monte Carlo simulation model is built in Arena. Using the collected and processed data, we use our model to address the main objectives of this thesis.

The remainder of this thesis is as follows. Chapter 2 introduces the role of warehousing inside the supply chain. It provides information about the different types of warehouses and their characteristics. This chapter continues with a full description of the different types of tasks inside one particular Versacold warehouse.

Chapter 3 describes all the used data collection methods. This chapter illustrates how tasks can be divided in multiple elements and how each of the elements is analyzed to determine the time to perform each task. All the elements linked to the body motions are analyzed using the MOST technique and all the elements attached to a machine are studied using a stopwatch.

Chapter 4 shows how the simulation model is built by exploiting all the information obtained in Chapter 3. This chapter also highlights the limitations of the proposed simulation model, which reproduces the operations for one customer and for a length of an entire year of operations in a 100% full pallet pick environment.

Chapter 5 presents the result of the simulation model together with an economic analysis to determine the best capacity levels to operate the warehouse. This chapter explains the different operations costs and how they vary in relation to the capacity utilization of the site.

Chapter 6 provides some concluding remarks and recommendations for the business during the low and high season period.

Chapter 2. Literature review

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request (Chopra and Meindl, 2013). The supply chain activities involve the transformation of natural resources, raw materials, and components into a finished product that is delivered to the end customer.

Figure 1 gives us an idea of where the warehouse is placed inside of supply chain management (SCM). It provides a perfect link between manufacturing services and the customers. (Saint Leo University, 2016). There is no activity that is more important that the other one, however we can notice that the warehouse is the step before to the delivery of the products to the customer.

In this chapter we first provide a brief summary of the most relevant concepts within logistics and warehousing used throughout this thesis. We then provide a brief description of the company and their main operations at one particular warehouse.

Figure 1 Supply Chain Flow

2.1 Warehousing

Warehousing has played a role in the storage and exchange of goods for centuries. Long term storage to provide products for future consumption has been a utility of warehousing both past and present (Keller and Keller, 2014). The reception, identification, inspection, verification, putting away, and the shipping of products are part of the warehouse functions.

The physical location may be referred to as a distribution center and is a storage facility that receives goods and products for the eventual distribution to consumers or other businesses. When we talk about warehouse management, we talk not only about the warehousing process, but also about the process of coordinating the incoming goods, the subsequent storage and tracking, and finally, their distribution to their proper destinations (Ackerman, 1997). These activities constitute usually the services offered by 3PL logistic companies such as Versacold.

2.1.1 Types of warehouses

Warehouses can be divided into five major groups, which are basically determined by the type of customers (Bartholdi and Hackman, 2014).

The different warehouse types are:

a. 3PL warehouse. This type of warehouse serves multiple customers from one facility. Different companies without storage space, with limited space or during the high season (like summer, where ice cream sales are higher and production volumes are high), could require the service from a 3PL warehouse to store their products.
b. Retail distribution centers. This type of warehouse typically supplies products to retail stores. The distribution centers will store large amounts of products and will

ship them to the different retail stores depending of the demand. In support of marketing campaigns, distribution centers have the possibility to "push" products to the stores to clear storage space. It is because of this that normally we see special prices at the end of the season.

c. Service parts distribution centers. This type is similar to the retail distribution center; the difference is that this type of warehouse holds spare parts for expensive capital equipment like automobiles or airplanes. Because of the type of products, it is recommended to forecast the activities, but unfortunately the demand for any particular part is hard to predict.

d. Catalog fulfillment or e-commerce. Amazon is the most popular e-commerce warehouse. This type of warehouse holds large amounts of products and normally the customers will place small orders (1 to 3 items) and the products have to be shipped as fast as possible.

e. Perishables warehouses. This type of warehouse handles delicate products like food, flowers or vaccines. Normally the temperature is really important to conserve the products and shipping process usually follows the FIFO (First-In-First-Out) or FEFO (First-Expired-First-Out) methods.

2.1.2 Warehouse Aisle Widths

AK Material Handling Systems Company (2019) gives a good explanation about the aisle widths for pallet rack systems. There are in general three types:

a. Wide Aisle (WA), with widths aisles between 11' to 13' or larger. This refers to the standard aisles width required for a sit-down counterbalanced forklift.

b. Narrow Aisle (NA), with widths aisles between of 8’ to 10’. Stand up trucks, reach trucks, and double deep reach trucks operate in these widths.
c. Very Narrow Aisle (VNA), with widths aisles of less than 6’. There is often some sort of guidance system (guide rail, wire guidance, or optical guidance) that is used. The types of trucks that can operate in this type of aisle are man-up order selectors, turret trucks and swing mast trucks.

There are always pros and cons involved on each type of aisles width types. (Redirack, 2019), a pallet racking manufacturer, based in UK, lists the following pros and cons:

Pros Aisle widths

a. Wide Aisle (WA),
    I. It is ideal for warehouse or industrial pallet racking.
    II. A standard counter balance truck or reach trucks can work on this type of aisles.
    III. Fast and easy for loading and unloading.
    IV. Easily adjustable.
b. Narrow Aisle (NA),
    I. Free up between 30 - 40% of the floor space given over to aisles in a wide aisle scheme.
    II. Accidental damage is reduced dramatically because of the use of a unique equipment to maneuver around.
c. Very Narrow Aisle (VNA),
    I. Free up to 45% of the floor space given over to aisles in a wide aisle scheme.

II. Specialized type of machines that lift higher and work faster than general lift trucks.

Cons Aisle widths

a. Wide Aisle (WA),
   i. Only utilize 40% of the available floor space.
   ii. Rack can be damage by employees turning inside of the aisle.
b. Narrow Aisle (NA),
   i. Risk of damaging products when storage products at high level locations.
c. Very Narrow Aisle (VNA),
   i. Only really expensive machines can operate inside of this type of aisles.
   ii. Especial rail and guides need to be installed.
   iii. High investment.

2.2 The company

According to the Versacold Logistics Service website, the company operates 31 distribution centers across Canada, with a combined storage capacity of 118 million cubic feet. All facilities meet HACCP requirements and have on-site CFIA offices and inspection rooms. (Versacold, 2019)

The products can be stored at a wide range of cold temperatures, ranging from -25°C to +5°C (-13°F to +41°F) (with ambient warehousing also available), and orders for all types of commodities can be prepared on-site. Many sites have rooms that can convert from freezer to cooler (and vice versa), based on customer requirements, increasing storage options and flexibility.

Warehousing is only one of the services that Versacold offers to the community and it is the focus of this research project. Figure 2 shows an overview of the warehousing operation tasks of Versacold's logistics services, which are also performed in most warehouses in North America. These tasks as well as the role of the employees preforming them are next described. For each of these tasks, the rates or productivity numbers shown below are based on experience and these change in relation to the layout of the warehouse.

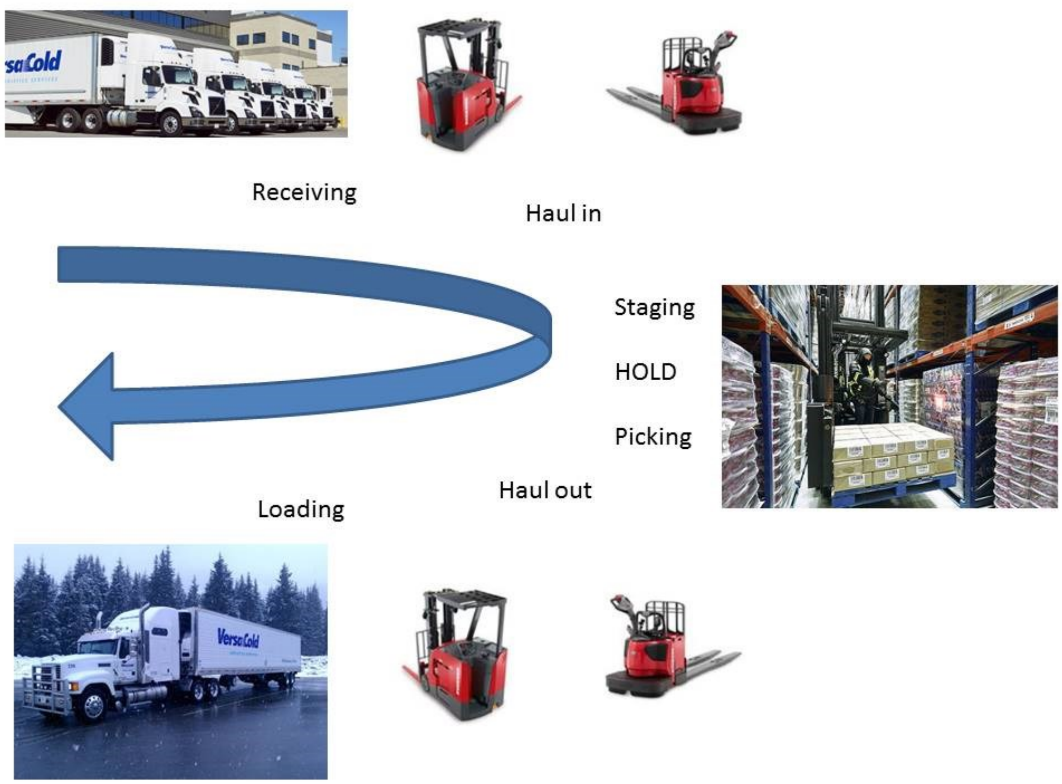

Figure 2 Versacold warehousing operations tasks

2.2.1 Loader and/or receiver: This employee is equipped with a dock stocker (DCK) and a RF gun as tools to load or unload pallets from trailer/truck. Figure 3 shows an employee in a DCK at the dock area. The employee oversees the following processes:

a. Receiving process: the employee unloads the trailers, places the pallets in the receiving staging lane and checks the conditions of the products. The rate for this operation is between 24 and 28 pallets/hour.

b. Loading process: the pallets placed at the dock are verified by the employee before loaded into the truck. The rate is 22-28 pallets/hour.

Figure 3 Loader and receiver using a dock stocker

2.2.2 Hauler: is the support of the receiving and loading processes and the connection between the dock and the storage area. In general, the employee performs this task with a double pallet jack (DPJ), however depending of the layout of a warehouse, this task can be performed using a triple pallet jack, dock stacker, or a reach tuck. Figure 4 depicts an employee using a DPJ at the dock area. The tasks to accomplish are:

a. Haul in: the employee takes the pallets (two by two) from the receiving staging and brings them inside the warehouse. The rate for this task is between 34 and 40 pallets/hour.

b. Haul out: the employee using a DPJ moves the pallets from the aisles or from the STO or dock area. The rate for this task is between 34 and 40 pallets/hour.

Figure 4 Hauler moving 2 pallets at the time form the receiving staging

2.2.3 Operators: This employee is equipped with a turret truck and a laser gun as tools to execute the staging and picking task. Figure 5 shows an employee using a turret truck in a middle of an aisle performing the task. The operator’s task productivity is not only affected by the horizontal travel, it is also impacted by the vertical travel. As we can see the pallets are not only located at the floor level and they can be placed at different elevation heights. Chapter 3 gives more detail about the different elevations or levels of the warehouse. Figure 6 shows how the pallets are placed in the aisle waiting to be stacked before a putaway, or to be moved to the shipping area after a full pallet pick task.

Figure 5 Operators putting away pallets on location or piking pallets from location.

a. Putaway: the operators pick up the pallets sitting at the middle of the aisles and place them at the nearest empty location. The rate for this task is between 17 and 22 pallets/hour.

b. Picking task: Using a RF gun, the employee needs to go to the location identified by the system and take the pallet out from the racking. The rate for a full pallet pick task is around 16 to 20 pallets/hour.

Figure 6 Pallets at the aisle waiting to be stacked, or to be moved to the shipping area.

2.3 Warehousing and constraints

As any business and any operations, warehouses face some constraints. When we look to the internal process, we can find constraints related to the building configuration, type of machines, and even union agreements. Even if union agreements are to defend the rights of the employees, this type of contracts could limit the planification of the operations.

When we talk about type of machine and labour constraints, and how the process could be improved, automation is always a topic on top of the table. Sobeys is a leader on automated warehousing process in the Canadian retail market (Kwon, 2013). With labour intense operations and serving a lot of small stores, the company needed a big change to continue in the market. This company owns multiple DC's where all the process is fully automated. But even fully automated processes like Sobeys have constraints, one of the constraints that is not possible to eliminate is the capacity. Nonmatter how big the warehouse is, the capacity is always going to be a challenge. Moreover, it is not clear whether they should work at full capacity or not.

There are pros and cons of working at full capacity in any business, when operations work at full capacity normally is to minimize the cost, avoid idle assets and even to show a good image amongst customers. But there is a negative side of working at full capacity, like adding stress to the employees, increasing repair costs, and reducing the ability to meet unexpected increases in demand.

2.4 others research

Simulation is used on the warehousing environment to answer to a lot of questions, most of them are focused on layout modification or possible operations improvements. Smith (2005) used a simulation model as design improvement decision, with his discrete-event simulation model, was allowed to increase the team's understanding of the process and suggest a couple of improvement as reduction of waiting times of the pallets inside of the process.

Kamaludin (2019), approach another important aspect inside of the warehouse operations, the inventory control. This simulation model not only represents the physical movement of the products, includes the flow of the information as well. This research highlight how important is the Bar-coding and radio-frequency identification (RFID) for the warehouse operations, which helps to eliminate the human error and easily track the movements and position of the pallets inside of the facility.

The examples beyond are good cases of how simulation could help in the research of solution for the general warehousing operations, but as other authors, they don’t contribute to solve the question of our current research which focus on determine at which levels of used capacity a warehouse is more profitable.

Wulfraat (2018), on the other hand mentioned that when the storage capacity of a warehouse overpasses the 85% of utilization, there is a reduction of the productivity in the warehouse. Normally when there is a reduction on the productivity, there is an associated increase in the cost, which means that the operations are working more, but are less profitable. Based on Wulfraat feedback, this information is based on experience on the field after his more than 30 years of consulting experience in logistics. This theory is aligned with our research and will be explored further on the following chapters.

Chapter 3. Data collection

This chapter describes the details of the full pallet pick and putaway tasks and the procedure to determine the operation time for each of them.

3.1 Standard process time

The standard process time is the time that an employee should take to perform a job (Spivak and Brenner, 2001). This standard process time is used in the industry to calculate the performance of the employees. To determine the operation time, the following techniques are required: the Maynard Operation Sequence Technique (MOST), time studies, and machine calibrations.

Table 1 shows all the elements included in a full pallet pick task and indicates the technique that is used to determine the time. Table 2 shows the putaway tasks, it is also split in multiple elements to be able to calculate the standard process time.

Sequence	Element Code	Description
1	MOST	Press key on the VMU key pad/RF device to select option
2	MOST	Press key on VMU keypad to advance to the next screen
5	MOST	Read details of the task received: location ID, Pallet ID,Case quantity
6	Calibration	Travel
7	MOST	Read the location number (6 digits) from the rack
8	MOST	Retrieve and Putaway Scanner from the Holster
9	MOST	Aim and activate scanner
10	Time study	Scan Time
11	MOST	Press key on VMU keypad to advance to the next screen
12	Time study	Turn In to Location TU
13	Calibration	Lift
14	MOST	Visual inspect pallet or locations for defects
15	Time study	Retrieve pallet from Level
16	MOST	Retrieve and Putaway Scanner from the Holster
17	MOST	Aim and activate scanner
18	Time study	Scan Time
19	MOST	Press key on VMU keypad to advance to the next screen
20	MOST	Enter Quantity Picked into VMU//RF
21	MOST	Read and Press"Y" key on the VMU key pad to confirm same drop location
22	Calibration	Drop
23	Time study	Turn Away from Location TU
24	MOST	Apply Label- TU
25	Calibration	Travel
26	Time study	Put Pallet on the Floor TU
27	MOST	Retrieve and Putaway Scanner from the Holster
28	MOST	Aim and activate scanner
29	Time study	Scan Time
30	MOST	Press key on VMU keypad to advance to the next screen
31	MOST	Aim and activate scanner
32	Time study	Scan Time
33	MOST	Press key on VMU keypad to advance to the next screen

Table 1 Elements of a full pallet pick task

Sequence	Element Code	Description
1	MOST	Press 1 on the VMU key pad/RF device to select option
2	MOST	Press key on VMU keypad to advance to the next screen
3	MOST	Read details of the task received: location ID / Pallet ID/Pick Zone
4	Calibration	Travel
5	MOST	Identify Pallets/cages
6	MOST	Visual inspect pallet or locations for defects
7	MOST	Retrieve and Putaway Scanner from the Holster
8	MOST	Aim and activate scanner
9	Time study	Scan Time
10	MOST	Press key on VMU keypad to advance to the next screen
11	Time study	Pick Up Pallet TU
12	Travel	Travel
13	MOST	Read the location number (6 digits) from the rack
14	Travel	Lift
15	MOST	Visual inspect pallet or locations for defects
16	Time study	Turn In to Location TU
17	MOST	Retrieve and Putaway Scanner from the Holster
18	MOST	Aim and activate scanner
19	Time study	Scan Time
20	MOST	Press key on VMU keypad to advance to the next screen
21	CDL-0586	TU Insert Level 3
22	Calibration	Drop
23	Time study	Turn Away from Location TU
24	MOST	Open and Close door time - TU
25	Time study	Corner 90 TU
26	MOST	Look both ways before entering intersection

Table 2 Elements of a putaway task

On Table 1, the elements 13, 15 and 22 are highlighted. The time of those elements depend on the storage location heights. Chapter 4 provide additional details about those elements.

3.2 MOST

The MOST technique is a predetermined motion time system. The American National Standards Institute (1972) describes a predetermined motion system as "*an organized body of information, procedures, techniques and motion times employed in the study and evaluation of manual work elements. The system is expressed in terms of the motions used, their general and specific nature, the conditions under which they occur and their previously determined performance times".*

Annex A shows an example of how the time for the element eight (Table 1), was determined. All other MOST elements are calculated using the same method.

3.3 Machine calibration

Calibration is the technique used to determine the speed of a machine. To arrive to the average speed, different samples need to be taken. Table 3 shows the different scenarios used for the turret truck speed calculation. A stopwatch was used to time for each scenario and the measurement was repeated three times for three different Turret truck. Annex B shows the results for each scenario and each machine.

The scenario "Unload 6 bays" calculates the speed of the turret truck during a travel of six bays distance without pallet. In the same way, the "Heavy Load 10 Bays" scenarios, calculates the speed of the turret truck for a travel distance of 10 bays with a heavy pallet. A heavy pallet is considered a pallet between 1800lbs and 2200 lbs.; a light pallet is around 900 lbs. and 1100 lbs.

Horizontal scenarios	**Lift scenarios**	**Drop scenarios**
Unload 6 Bays	Unloaded Lift B	Unloaded Drop B
Unload 8 Bays	Unloaded Lift D	Unloaded Drop D
Unload 10 Bays	Unloaded Lift F	Unloaded Drop F
Light Load 6 Bays	Unloaded Lift B	Light Load Drop B
Light Load 8 Bays	Unloaded Lift D	Light Load Drop D
Light Load 10 Bays	Unloaded Lift F	Light Load Drop F
Heavy Load 6 Bays	Light Load Lift B	Heavy Load Drop B
Heavy Load 8 Bays	Light Load Lift D	Heavy Load Drop D
Heavy Load 10 Bays	Light Load Lift F	Heavy Load Drop F

Table 3 Calibration turret truck scenarios

Figure 7 shows a turret truck from Raymond handling corporation (2019). This machine is defined as an operator-up, very-narrow-aisle truck (VNA) pallet carrying counterbalanced fork truck with an articulating carriage allowing the forks to rotate 180º within the storage aisle.

Figure 7 Turret truck Machine

Table 4 shows the final calibrations results or speed of the machine. An additional 9% is added to the total results because of the fatigue allowance and delays that the process has. This factor is important to add, because every human being gets tired after any physical effort and this impacts the average performance. Kroemer et al. (2001) defines the fatigue as combination of biochemical events that perturbs the regular performance of the body.

Scenarios (tmu/in)	One Number Avg.	Includes Fatigue Allowance and Delays(9%)
Long Travel Avg.	0.408000	0.444720
Lift	2.172000	2.367480
Drop	2.207000	2.405630

Table 4 Turret truck speed

Once the speed of the machine is determined, the general lift and drop time can be calculated for each elevation. Table 5 shows the time to lift and drop a pallet in seconds for each of the seven different elevations of the warehouse.

Levels	High inches	Lift Time sec	Drop Time sec	SUM lift and drop

[redacted]

Table 5 Lift and drop times

3.4 Time study - travel time

For some elements it is not possible to use the MOST technique, for those elements (excluding the lift and drop), it is necessary to use the time study.

Heap John (2010) defines that “time study” is a structured process of directly observing and measuring human work using a timing device to establish the time required for completion of the work by a qualified worker when working at a defined level of performance. This technique consists of basically following an employee and stopwatch every machine movement (or element) that is required.

Annex C shows the times for all the elements that are calculated using this technique. The number of observations varies according to the variance between samples. A good average result will present a relative error inferior to 5%.

The following formula is used to calculate the relative error:

$$e = \frac{1.96.stdv}{\sqrt{N} * avg}$$

Table 6 resume the results form Annex C for the retrieved (full pallet pick) or insert (putaway) pallets from the rack. The 9% fatigue allowance and delays are included as well.

Insert L 1	Insert L 2	Insert L 3	Insert L 4	Insert L 5	Insert L 6
11.8	14.3	13.5	14.2	16.0	20.1
Retrieve L 1	**Retrieve L 2**	**Retrieve L 3**	**Retrieve L 4**	**Retrieve L 5**	**Retrieve L 6**
12.2	12.5	12.8	12.9	13.0	14.7

Table 6 Insert and retrieve times per level

As shown in Table 4, the horizontal speed of a turret truck can be defined as 0.44 tmu/in. The width of a bay is 8.66 ft. The employee usually travels one bay before he arrives at the location of the next task. For this reason, a bay width is used to calculate the horizontal travel. Taking this information in consideration it could be concluded that the horizontal time as a total of 3.32 sec.

Chapter 4. Simulation Model

In this chapter we explain all the components required by the simulation model used to achieve the objectives of this research. We first describe the assumptions and the fundamentals of the discreate-event simulation model implemented in ARENA. We then provide details on the modeling of the different tasks (or activities) considered in the simulation such as product arrivals, putaway process, holding, and full pallet pick.

4.1 Assumptions and Fundamentals

The model assumes a year of 365 workdays with a total of eight hours per day. Based on the company's information, not all the eight hours are working hours. In reality 18.75% of the time is assigned to breaks, lunches and warm-ups. Therefore, the simulation model only uses a total of six-point-five (6.5) work hours per day. Figure 8 shows the Arena basic simulation setup and Annex D shows the detailed structure of the model.

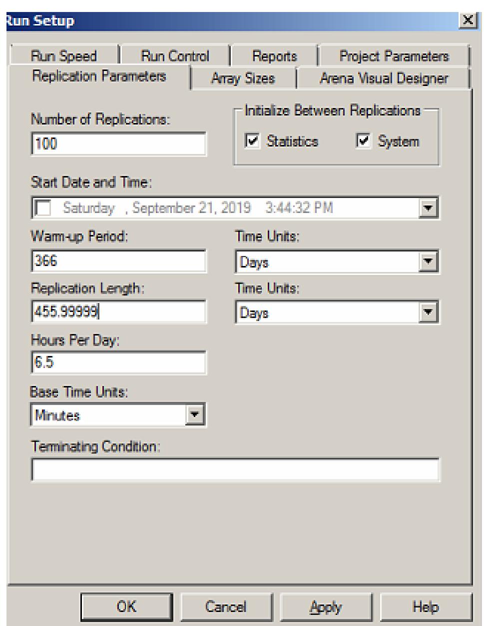

Figure 8 Arena setup for period Q1

The total number of replications is set up as 100, this value was decided after the analysis of the results of different simulations with different replications. We noticed that the half width of the results did not variance a lot after 80 replications and the results were consistence. Based on this and because the time to run the simulations was acceptable for 100 replications, we decided that was the best for the objective of this research.

Figure 8 shows a warm-up period of 366 days and replication length of 455.9999 days, with this set-up we were able to collect data for the first period of the year, the first 90 days of our simulations. To get the second year we changed the set-up to 456 days as warm-up period and replication length of 547.9999 days. Q3 used a warm-up period of 548 days, replication length of 638.9999 days and Q4 a warm-up period of 639 days with a replication length of 730.9999 days.

The rates showed in Chapter 3 are based on experience and they change in function of the layout of each warehouse. To have better inputs for the simulation model, the process time is calculated based on the operations of the specific warehouse selected for this study. The simulation model takes into consideration a narrow aisle storage site, in a 100% full pallet pick environment.

The description of the process showed in Chapter 3, confirm clearly that the putaway and the picking processes are the most time-consuming tasks. These two tasks are the focus of the operations data collection and the simulation model, because they are identified in the industry as the bottleneck of the operations. The putaway and full pallet pick cannot be performed at the same time, because the aisles (narrow aisles) must be clear to be able to perform each type of task.

To have a better understanding of the simulation model, it is necessary to recall some concepts used in simulation (Kelton, 2010):

a. Entities are the dynamic objects in simulation. In this model the entities are the pallets received, staged and shipped.

b. Attributes are used to individualize entities. It is a common characteristic of all entities. The arrival pallets are identified as Products 1, 2, 3, and 4.

c. Variables are a piece of information that reflects some characteristics of the system.

d. Resources are things like personnel, equipment or space. An entity seizes a resource when it is available and releases it when finished. An employee using a turret truck is considered as one resource and is used to perform the putaway and/ or full pallet.

4.2 Process Flow chart

The flow chart on figure 10 gives a high level explenaitions of the activities of the simulation model and how the product move inside of the process. Annex D shows the detailed structure of the model. As mentioned at the beginning of this chapter, only the turret truck activities made part of the simulation process.

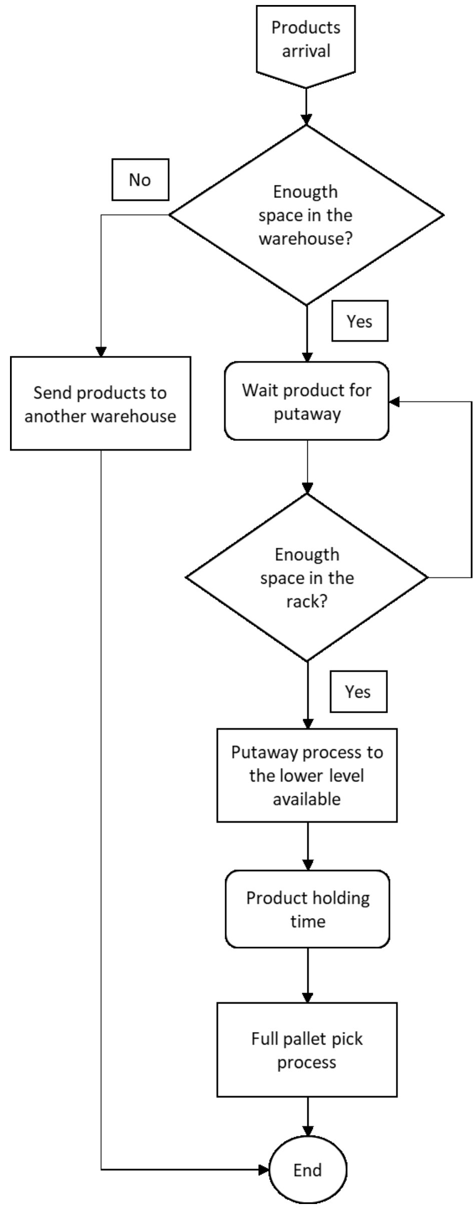

Figure 9 Process Flow chart

4.3 Product arrivals

Our simulation model uses the input information of one (uneditifified) customer. Each day, this customer sends a number of pallets that arrive in trailers to be stored in the warehouse. Each pallet contains one of four types of products. The following table shows the distribution of the products en each pallet based on the data observed last year.

Product type	Distribution %
Product 1	20.9%
Product 2	13.9%
Product 3	37.5%
Product 4	27.7%

Table 7 Arrivals distribution of products

With the help of the *Input Analyzer* and *FitAll* function, we selected the distribution with the smallest squared error. In chapter 5 we show the validtion process and which suggests that distributions are representative.

Table 8 sumarrizes the information associated with the number of arrival pallets received per day for each of the periods (quarters). In order to be more consistent with the results, the first year is considered as a warm-up period and the data used to analyse the obtained results are the ones starting at day 366 on the simulation model.

Quarter	Start time (Day)	End time (Day)	Arrival rate (pallets)
Q1 Warm-up	0	90	TRIA(29.5, 66.1, 72.5)
Q2 Warm-up	91	182	TRIA(37.5, 84.9, 105)
Q3 Warm-up	183	273	TRIA(64.5, 75, 125)
Q4 Warm-up	274	365	TRIA(33.5, 38, 80.5)
Q1	366	456	TRIA(29.5, 66.1, 72.5)
Q2	457	548	TRIA(37.5, 84.9, 105)
Q3	549	639	TRIA(64.5, 75, 125)
Q4	640	731	TRIA(33.5, 38, 80.5)

Table 8 Distribution of arrival of pallets per day distribution

Figure 10 represents the setup for the arrival of products during the second period of the year. Because of the seasonality of this customer, the “Entities per arrival” changes based on the consider period of the year. Annex E shows the input anylizer results.

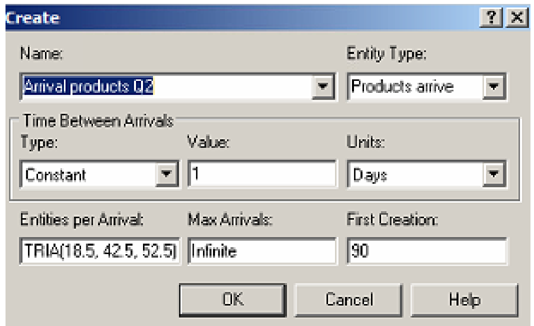

Figure 10 Arrivals products during the Quarter 2 of the year

4.4 Putaway process

As shown on Table 5, the putaway time depends on the elevation of the selected position. Based on time studies, MHE calibrations, and MOST elements, we estimate the putaway times by fitting the input data into continuous distribution functions. Table 9 shows a summary of the putaway times per level. These results are used as a process input information. Annex F shows the input analyzer results.

The putaway as the full pallet pick process time, includes variable and constant times. Using as an example, level B from table 9, the 57.2 seconds is considerate as the constant time. This value is the sum of the horizontal travel time, vertical travel time and the employee movements. The travel time is coming from the calibration study and the employee movements from MOST study.

On the other hand, the variable time, is split in two. The first part "(8+ERLA (0.579,8))"; which is coming from the machine general movements as turn-in and turn out and the value is the same for all levels. For the second part of the variable time "(NORM(13.1, 1.63)", we have the time coming from the insert for the putaway or form the retrieve for the full pallet pick, which change based on the level. To obtain the distribution of this times we used *Input*

Analyzer and *FitAll* function as explained on point 4.3. Figure 11 shows the setup for the putaway task at level A.

Level	Put away times (seconds)
A	41.2+(8 + ERLA(0.579, 8))+(8.27 + LOGN(2.54, 1.47))
B	57.2+(8 + ERLA(0.579, 8))+(NORM(13.1, 1.63))
C	72.1+(8 + ERLA(0.579, 8))+(NORM(12.4, 0.961))
D	87.1+(8 + ERLA(0.579, 8))+(10.2 + 5.36 * BETA(1.8, 1.73))
E	102+(8 + ERLA(0.579, 8))+(10 + 8.81 * BETA(2.31, 2.08))
F	117.3+(8 + ERLA(0.579, 8))+(12 + WEIB(7.18, 2.21))
G	132.2+(8 + ERLA(0.579, 8))+(12 + WEIB(7.18, 2.21))

Table 9 Putaway times per level

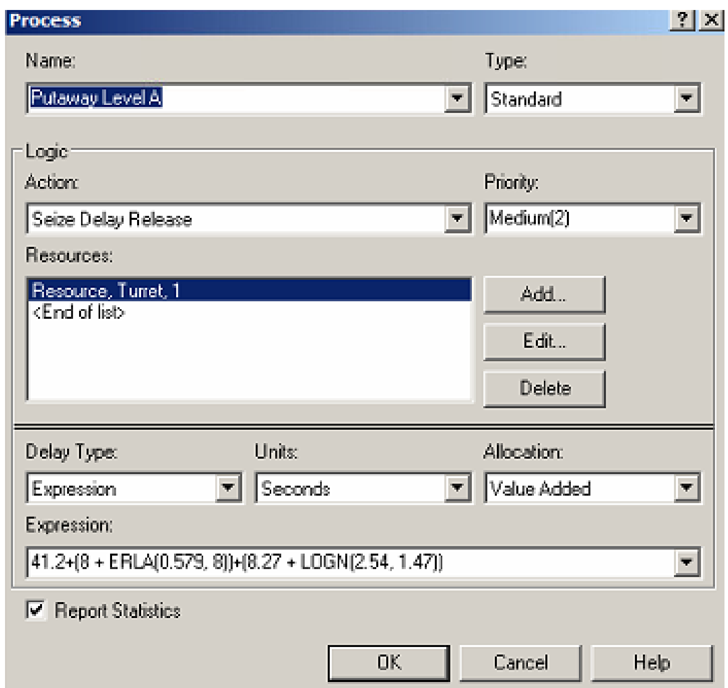

Figure 11 Arena process set-up for Putaway level A

4.5 Holding time

Based on the customer information and with the use of the input analyzer tool, it is possible to determine the expected holding time for each product. The holding time represents the time that the products will stay inside the warehouse. Once the pallets reach this time, the products will be processed as a full pallet pick task and shipped to the customer.

Table 10 summarizes the distribution of holding time in days for each product per quarter. To obtain the distribution of this times we used *Input Analyzer* and *FitAll* function as explained on point 4.3. Annex G shows in details the input analyzer results.

Product and Quarter	Holding time
Product 1 Quarter 1	-0.5 + LOGN(4.65, 3.35)
Product 1 Quarter 2	-0.5 + 30 * BETA(1.17, 4.05)
Product 1 Quarter 3	0.5 + WEIB(8.05, 1.22)
Product 1 Quarter 4	NORM(6.01, 3.36)
Product 2 Quarter 1	-0.5 + GAMM(2.94, 1.8)
Product 2 Quarter 2	-0.5 + WEIB(7.67, 1.2)
Product 2 Quarter 3	1.5 + 35 * BETA(1.28, 3.29)
Product 2 Quarter 4	-0.001 + WEIB(8.21, 0.827)
Product 3 Quarter 1	-0.5 + GAMM(2.19, 1.94)
Product 3 Quarter 2	-0.5 + 27 * BETA(0.799, 4.01)
Product 3 Quarter 3	-0.5 + ERLA(2.83, 3)
Product 3 Quarter 4	-0.5 + 38 * BETA(2.36, 11.3)
Product 4 Quarter 1	-0.5 + LOGN(4.45, 4.44)
Product 4 Quarter 2	-0.5 + WEIB(6.17, 1.33)
Product 4 Quarter 3	-0.5 + GAMM(4.47, 2.17)
Product 4 Quarter 4	0.5 + WEIB(8.35, 1.47)

Table 10 Holding time per day per period.

4.6 Full pallet pick

Similar to Section 4.4, the operators use a turret truck to perform the full pallet pick. Depending of the level, the full pallet pick time varies. Based on the time studies, MHE calibrations and MOST elements, as explained for the putaway process on point 4.4. Table

11 displays the distribution functions used to estimate full pallet pick times per level. Annex H shows the input analyzer results. Figure 12 shows the simulation setup for the full pallet pick task at level A.

Level	Full pallet pick times (seconds)
A	58+(NORM(13, 1.58))+(TRIA(9.04, 11.5, 13))
B	74+(NORM(13, 1.58))+(10 + 3.95 * BETA(0.957, 1.5))
C	88.9+(NORM(13, 1.58))+(NORM(11.7, 1.26))
D	103.9+(NORM(13, 1.58))+(10 + 3.7 * BETA(1.1, 1.17))
E	118.8+(NORM(13, 1.58))+(10.7 + 2.2 * BETA(0.653, 0.563))
F	134.1+(NORM(13, 1.58))+(NORM(13.5, 1.21))
G	149+(NORM(13, 1.58))+(NORM(13.5, 1.21))

Table 11 Full pallet pick times per level

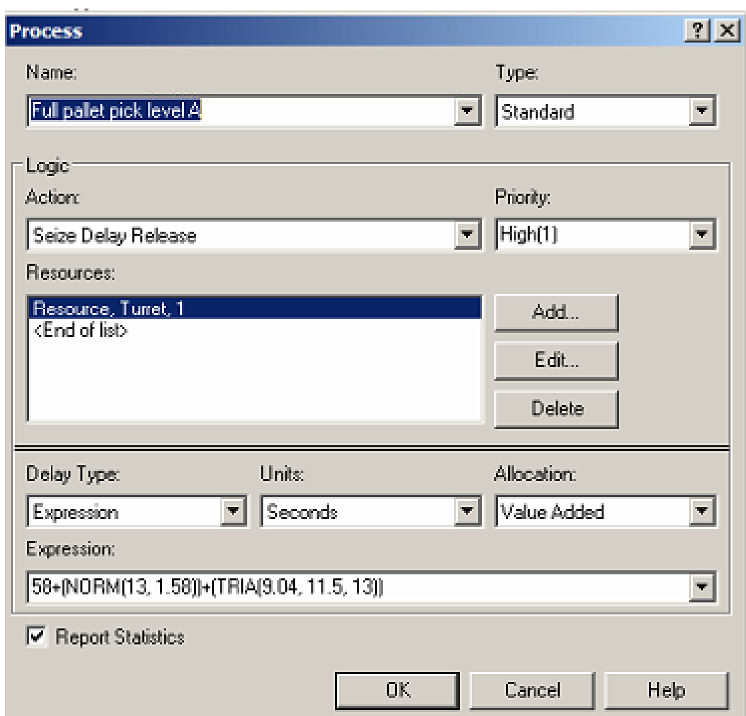

Figure 12 Arena process set-up for Full pallet pick level A

4.7 Validation process

The objective of any simulation model is to represent as close as possible the reality, but the simulation model is valid only if the model is an accurate representation of the actual system. Law (2007). For the validation of our current model, we used the "confidence intervals for means" technique.

Table 12 shows 12 different periods of time, where we compared the input results from the simulation (sample) vs my original data.

Period	Sample	Real	Difference
1	881.3	860	-21.3
2	876.2	890	13.8
3	875.5	866	-9.5
4	874.9	896	21.1
5	874.5	857	-17.5
6	880.8	856	-24.8
7	878.8	864	-14.8
8	873.9	890	16.1
9	648.2	700	51.8
10	609.7	638	28.3
11	532.0	528	-4.0
12	492.8	474	-18.8

Table 12 Difference between real data and simulation samples

The mean of the difference of the values from table 12 is equal to 1.78 and the standard deviation is equal to 24.12. Using the t student table, with a confidence level of 95%, the value is 2.2. The following formula is used for a one-sample t interval for a mean:

$$\bar{x}_{\text{Diff}} \pm t^* \cdot \frac{s_{\text{Diff}}}{\sqrt{n}},$$

Using the beyond, we obtain an interval of (-13.06, 17.03). This interval contains the value 0, which represents no difference between the real and simulation values. If the entire interval had been all positive or negative values, then it would mean a difference between the real and simulation values.

Chapter 5. Analysis of Computational Experiments

In this chapter we provide the results of a computational experiments performed to evaluate the relationship of profit as a function of the utilization level of a warehouse. In the first part of this chapter, we provide detailed computational results obtained with our simulation model which considers a single customer and one warehouse. In the second part we provide an economic analysis of the costs and the revenues associated with the warehouse operations.

5.1 Computational results of ARENA

As described in Sections 4.4 and 4.6, there are different arrival rates and holding times for each quarter of the year. For this reason, the results of our ARENA simulation model are analyzed per quarter as well. The following points provide the basic run setup of the simulation model:

1. Number of replications: 100
2. Hours per day: 6.5 hours per day.
3. Base units: minutes.
4. Time units: days
5. 4 different types of products.
6. Capacity of 868 pallets positions divided in seven levels of 124 pallets position each one.
7. One turret to perform the putaway and full pallet picks

5.1.1 Analysis of results for period Q1

During period Q1, the warehouse receives and ships a total of 5,001 and 4,772 pallets, respectively. We can see that the average warehouse occupancy is only at 42.34%. As expected, at this occupancy percentage, levels A and B are the ones with more pallet positions and the average utilization of the turret truck is at 49.78%. Table 13 summarizes the results for period Q1 and annex I shows all the details.

Inbound products		Outbound products	
Type	**Quantity**	**Type**	**Quantity**
Product 1	1044	Product 1	1010
Product 2	697	Product 2	653
Product 3	1875	Product 3	1798
Product 4	1385	Product 4	1311
Total inbound products	**5001**	**Total outbound products**	**4772**

Occupancy			
Level	**Quantity**	**Capacity**	**Utilization**
A	122.09	124	98.46%
B	120.04	124	96.81%
C	105.73	124	85.27%
D	19.66	124	15.85%
E	0	124	0.00%
F	0	124	0.00%
G	0	124	0.00%
Total	**367.52**	**868**	**42.34%**

Table 13 Results for period Q1

5.1.2 Analysis of results for period Q2

During period Q2, the warehouse starts to have more volume. The average occupancy level increases from 42% to 61%. The turret truck shows a 76.09 % average utilization. A total of 6,872 pallets were received and 6,713 were shipped. Table 14 shows a summary for the Q2 period and annex J shows all the results of the model.

Inbound products		Outbound products	
Type	**Quantity**	**Type**	**Quantity**
Product 1	1430	Product 1	1393
Product 2	957	Product 2	930
Product 3	2581	Product 3	2530
Product 4	1904	Product 4	1860
Total inbound products	**6872**	**Total outbound products**	**6713**

Occupancy			
Level	**Quantity**	**Capacity**	**Utilization**
A	122.4	124	98.71%
B	122.23	124	98.57%
C	121.25	124	97.78%
D	111.96	124	90.29%
E	44.44	124	35.84%
F	0.05	124	0.04%
G	0	124	0.00%
Total	**522.33**	**868**	60.18%

Table 14 Results for period Q2

5.1.3 Analysis of results for period Q3

For period Q3, the average occupancy level increases to 94.84% and the turret truck shows a 98.04% average utilization. We call this period “High season”. In periods like this one, operations could run over 100% of their capacity, which means that some pallets will be stored in the middle of the aisles, staging areas and/or dock areas. The high season not only impacts the warehouse business but impact the economy in general. Based on the study realized by Guillemette et al. (2000), during the high season more jobs are offered, and seasonal employees are available on the market, which helps companies to continue to service the customers without impacting the operations.

Table 15 shows a summary of the result for period Q3 and annex K shows all the results of the model.

Inbound products		Outbound products	
Type	**Quantity**	**Type**	**Quantity**
Product 1	1660	Product 1	1582
Product 2	1103	Product 2	1048
Product 3	2982	Product 3	2842
Product 4	2196	Product 4	2102
Total inbound products	**7941**	**Total outbound products**	**7574**

Occupancy			
Level	**Quantity**	**Capacity**	**Utilization**
A	123.08	124	99.26%
B	123.05	124	99.23%
C	122.98	124	99.18%
D	122.8	124	99.03%
E	121.16	124	97.71%
F	112.23	124	90.51%
G	97.88	124	78.94%
Total	**823.18**	**868**	**94.84%**

Table 15 Results for period Q3

The simulation model assumes that the warehouse can work at a 110% of its capacity. Before hitting the 110% of capacity, if the site needs extra labour, employees are called to work “over time”. The over time is normally payed at a rate of 150% from the normal hourly rate.

If the company is already at 110%, and it cannot receive any more products, the products are refused and sent to another warehouse to be stored. The cost attached to this option is around $1,500 dollars per trailer. The model assumes that one trailer transports a maximum of 26 pallets per trip. For other companies, this cost could be higher or probably not possible. If a client is not happy with the idea of having his products in different sites, it could take the decision of cancelling the contract.

5.1.4 Analysis of results for period Q4

For period Q4, the average warehouse occupancy decreases to 45.20%. The turret truck shows a 50.81 % average utilization. The total number of pallets receive are less than the number shipped, which means that the high season is over. Table 16 shows a summary of the results for Q4 and Annex L shows all the results of the model.

Inbound products		Outbound products	
Type	**Quantity**	**Type**	**Quantity**
Product 1	934	Product 1	1066
Product 2	625	Product 2	726
Product 3	1678	Product 3	1917
Product 4	1236	Product 4	1413
Total inbound products	**4473**	**Total outbound products**	**5122**

Occupancy			
Level	**Quantity**	**Capacity**	**Utilization**
A	121.77	124	98.20%
B	120.82	124	97.44%
C	102.28	124	82.48%
D	17.13	124	13.81%
E	10.51	124	8.48%
F	9.91	124	7.99%
G	9.94	124	8.02%
Total	**392.36**	**868**	**45.20%**

Table 16 Results for period Q4

5.1.5 Analysis of results for the entire planning horizon

After seen the behavior over the four different quarters, it can be deduced that there is a relationship between the warehouse occupancy and the utilization of the Turret truck. Table 17 shows a summary of the data for each month of the year which shows the strong relationship between the warehouse occupancy and the turret utilization.

Start	end	Month	Warehouse occupancy	Turret truck utilization	Inbound pal	Outbound pal	Holding pal	Avg Productivity
0	31	1	38.25%	45.51%	1654.4	1449.1	332.0	22.1
31	59	2	44.04%	51.29%	1537.2	1535.4	382.3	21.4
59	90	3	43.99%	51.29%	1703.4	1700.7	381.8	21.4
90	120	4	56.95%	71.94%	2197.1	2057.0	494.3	19.8
120	151	5	61.13%	77.07%	2309.5	2309.1	530.6	19.3
151	181	6	61.25%	77.32%	2242.0	2242.5	531.6	19.3
181	212	7	83.50%	93.39%	2694.3	2347.4	724.7	17.5
212	243	8	106.37%	99.99%	2713.9	2646.1	923.3	17.1
243	273	9	108.47%	100.00%	2632.8	2632.4	941.5	17.5
273	304	10	59.32%	65.93%	1572.4	2163.8	514.9	18.3
304	334	11	40.34%	45.61%	1494.8	1490.0	350.2	21.8
334	365	12	40.51%	45.86%	1543.2	1544.8	351.7	21.8

Table 17 Yearly results by month

Figure 13 shows that during the periods where the occupancy of the warehouse is high, the % of the Turret utilization is high as well.

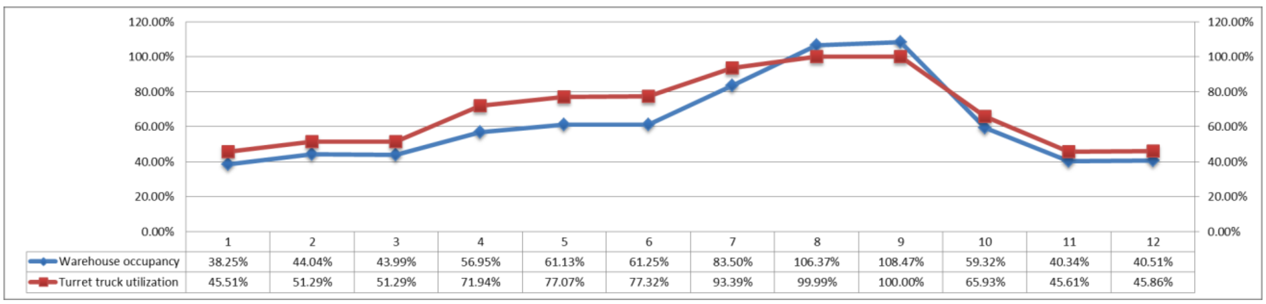

Figure 13 Warehouse occupancy vs Turret truck utilization

There is a relationship between the warehouse occupancy and the productivity as well. Figure 14 demonstrates that whenever the occupancy of the site increase, the productivity of the turret decreases. This is because more products are stored in the warehouse, which means that upper levels are needed. It takes more time for the turret truck to perform a putaway or a full pallet pick if the pallets are on the upper levels. During the high season periods, we can see how the productivity decreases by about 20% in comparison with the months with low occupancy. On the other hand, Figure 13 shows that during the low season the machine is idle around 50% of the time.

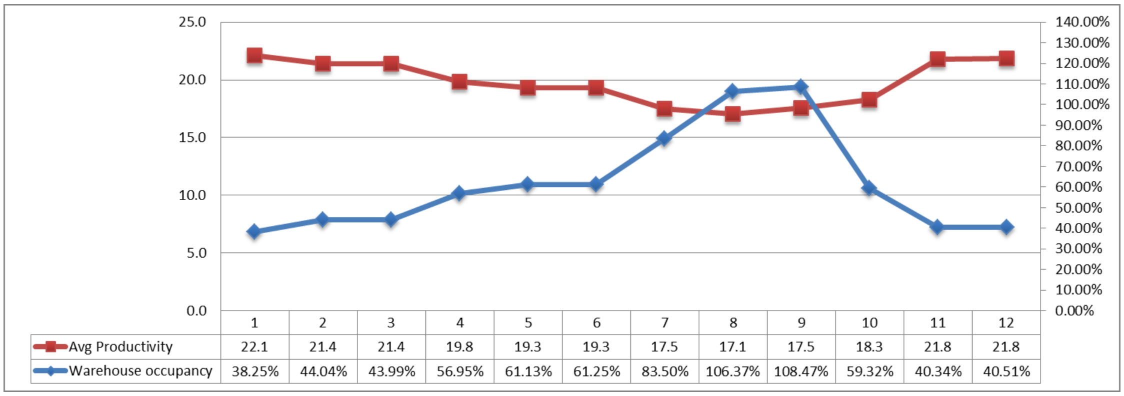

Figure 14 Warehouse occupancy vs Avg turret truck productivity

5.2 Economic analysis

Table 18 shows the fixed costs attached to the warehouse operations for this specific customer account. We assume that only one turret truck and one employee work for this customer. The employee will be payed, even if there is no work to do. Normally during the low season, the company takes the extra time to train their employees, reorganize the warehouse or do other kind of tasks not related to the warehousing operations.

FIX COST	**$**
Employee cost per hour	$ 35
Work hours per shift	8
Work days per month	28
Employee cost per month	$ 7,840
MHE monthly lease	$ 4,550
Monthly fix cost	**$ 12,390**

Table 18 Distribution of the fixed cost

For variable costs like warehouse electricity, office employees and other type of costs, the company simply applies a total of 34% over the total revenue. This variable cost can be calculated in different ways and is up to each company to determine the best way to do it.

As mentioned, an extra cost is charged when the warehouse is running over 100%. In such cases, a small portion of pallets are frequently waiting for space and they need to be temporarily placed in the middle of the aisles, staging areas or even send them to other facility. This extra cost is also added to the variable cost.

5.2.1 Revenue

There are three basics revenue sources when we talk about a 100% full pallet pick environment warehouse. For the purposes of this research, the following charges are the ones that have been taken into consideration:

a. Inbound handling: This is the price that the customer is charged every time that one pallet is received in the warehouse. For the calculation of the total revenue, a value of 8$ is applied for the inbound pallets.
b. Outbound handling: The customer will be billed at a rate every time that one pallet leaves the warehouse. For the calculation of the total revenue, a value of 8$ is applied for the outbound pallets
c. Storage: This is the rate that a warehouse will charge the customer for keeping the products inside of the facilities. For the calculation of the total revenue, a value of 30$ is charged to the total average holding pallets per month.

The charges above are dependent to the contracts and the type of customer. The values do not represent any Versacold establish rates for any customer, a customer with a high turnover ratio will probably have a lower storage rate than a customer who leaves his products “sitting” for long periods of time.

5.2.2 Profit

Once the client is charged and the costs of running the operations are applied, it is possible to calculate the profit of the warehouse for one specific customer. Table 19 shows the details of the revenue for the total pallets received, shipped and stored per month. This table also shows the cost of running the operation, including, fixed, variable and extra cost. We note that the extra cost is only applied for months 8^{th} and 9^{th}. This is due to the fact during these months the warehouse is usually running over its capacity and the amount of resources cannot process all products during the regular hours of work.

Month	$	1	2	3	4	5	6	7	8	9	10	11	12
Warehouse occupancy		38.3%	44.0%	44.0%	56.9%	61.1%	61.2%	83.5%	106.4%	108.5%	59.3%	40.3%	40.5%
REVENUE													
Inbound Handling	$8	$13,235	$12,297	$13,627	$17,576	$18,476	$17,936	$21,554	$21,711	$21,062	$12,579	$11,958	$12,345
Outbound handling	$8	$11,593	$12,283	$13,605	$16,456	$18,473	$17,940	$18,779	$21,169	$21,060	$21,060	$11,920	$12,358
Storage	$30	$9,961	$11,469	$11,455	$14,829	$15,918	$15,949	$21,742	$27,699	$28,244	$15,448	$10,505	$10,550
TOTAL REVENUE		**$34,789**	**$36,050**	**$38,687**	**$48,861**	**$52,866**	**$51,825**	**$62,076**	**$70,579**	**$70,366**	**$49,086**	**$34,383**	**$35,253**
COST													
Monthly cost (MHE and Manpower)		$ 12,390	$ 12,390	$ 12,390	$ 12,390	$ 12,390	$ 12,390	$ 12,390	$ 12,390	$ 12,390	$ 12,390	$ 12,390	$ 12,390
Variable cost	34%	$11,828	$12,257	$13,154	$16,613	$17,975	$17,620	$21,106	$23,997	$23,924	$16,689	$11,690	$11,986
Over time cost									$ 3,661	$ 4,425			
Send pallets to other warehouse									$ 9,000	$ 13,500			
TOTAL COST		**$ 24,218**	**$ 24,647**	**$ 25,544**	**$ 29,003**	**$ 30,365**	**$ 30,010**	**$ 33,496**	**$ 49,048**	**$ 54,239**	**$ 29,079**	**$ 24,080**	**$ 24,376**
PROFIT		**$ 10,571**	**$ 11,403**	**$ 13,144**	**$ 19,858**	**$ 22,502**	**$ 21,814**	**$ 28,580**	**$ 21,531**	**$ 16,127**	**$ 20,007**	**$ 10,303**	**$ 10,877**

Table 19 Total profit per month

Looking at the results, we can observe that the warehouse is more profitable when the volume is at 83.5%. Figure 15 shows that for the first seven months the profits of the warehouse rise with the occupancy level, but once it hits the 83.5% the revenue it starts to drop because the occupancy is over 100%. These results support the claims made in Chapter 2 which state that when storage capacity of a warehouse overpass the 85% of its capacity, there exist a reduction of productivity and profits.

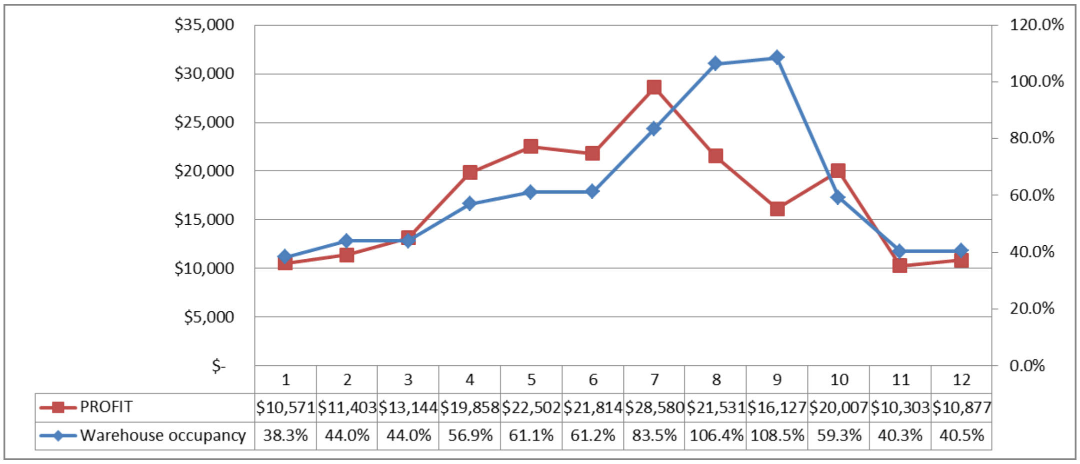

Figure 15 Monthly profit vs warehouse occupancy

5.2.3 Extra machine vs. over time

When the productivity decreases and the proceeded volumes increase, companies are interested in analyzing the impact and economic implications of adding more resources to the operations. We must keep in mind that the turret trucks are customized machines and cannot be leased for a short period of time, the company needs to buy or lease it for at least four years.

As we can see in Table 19, the monthly cost for the machine and the operator is $12,900. Adding another machine will double the fixed cost but will eliminate any type of extra cost. Unfortunately, at the end this will not be enough to increase the total profit of the month.

Another point to take into consideration is that this additional cost will impact all the months, and as we see it in Chapter 4, only on the eighth and the ninth month, the machine hits the 100% of utilization. As a conclusion, adding an extra machine for this kind of customer will only increase the cost without really increasing the profit.

Table 20 compares the results for the seventh month at 83,5% of occupancy and only working with one machine versus the ninth month at 89,4% of occupancy and working with two machines, we can easily conclude that even if the revenue is higher, the profit is better with less volume and only with one machine.

		1 machine	2 Machines
Month	**$**	**7**	**9**
Warehouse occupancy		**83.5%**	**89.4%**
REVENUE			
Inbound Handling	$8	$21,554	$21,062
Outbound handling	$8	$18,779	$21,060
Storage	$30	$21,742	$28,244
TOTAL REVENUE		**$62,076**	**$70,366**
COST			
Monthly cost (MHE and Manpower)		$ 12,390	$ 24,780
Variable cost	34%	$ 21,106	$ 23,924
Over time cost			
TOTAL COST		**$ 33,496**	**$ 48,704**
PROFIT		**$ 28,580**	**$ 21,662**

Table 20 One machine vs. two machines comparison different periods.

Table 21 compares the results for the seventh month at 83,5% of occupancy and only working with one machine versus the same month but using 2 machines. As we can notice, the total revenue does not change significantly, this is because for the seventh month, the occupancy of the turret truck was around 94% and now with 2 machines we are just splitting the work between the two machine and having more idle time. On the other side, the total cost increased because of the new machine which drowns the total profit.

		1 machine	2 Machines
Month	**$**	**7**	**7**
Warehouse occupancy		**83.5%**	**80.2%**
REVENUE			
Inbound Handling	$8	$21,554	$21,554
Outbound handling	$8	$18,779	$19,534
Storage	$30	$21,742	$20,874
TOTAL REVENUE		**$62,076**	**$61,963**
COST			
Monthly cost (MHE and Manpower)		$ 12,390	$ 24,780
Variable cost	34%	$ 21,106	$ 21,067
Over time cost			
TOTAL COST		**$ 33,496**	**$ 45,847**
PROFIT		**$ 28,580**	**$ 16,115**

Table 21 One machine vs. two machines comparison same period.

5.2.4 High season behavior

Until now it could be concluded that at 83.5 % of occupancy, the site is at his most profitable level. If we look carefully, we can note that there is a big gap between the results from the previous month (sixth month) and the month after (eighth month). Based on this, we decide to give a closer look to the high season period to determine if 83.5 % is a reasonable number to answer the question of this research, *at which occupancy level is the company more profitable?*

To have a better look at what is happening during the high season period, the run rate of the simulation model is modified from 30 days (or depends of the month) to a length on 10 days. Table 22 presents the results for a total of 80 days; each column represents a period of 10 days inside of the high season period. As we can see, the warehouse is at its most profitable period when the occupancy is at 88.7% and in a second stage when is at 83.9%.

With these results and with the results showed in chapter 5.3, it is possible to establish that a warehouse is more profitable when it runs in an occupancy between 83.5% and 88.7%.

Period of 10 days	$	1	2	3	4	5	6	7	8
Warehouse occupancy		109.1%	102.6%	106.6%	108.0%	100.5%	97.1%	88.7%	83.9%
REVENUE									
Inbound Handling	$8	$7,010	$7,004	$6,999	$6,996	$5,185	$4,877	$4,256	$3,942
Outbound handling	$8	$6,397	$6,598	$6,811	$6,956	$7,300	$7,300	$7,451	$7,364
Storage (10 days)	$10	$9,471	$8,902	$9,256	$9,378	$8,724	$8,428	$7,697	$7,281
TOTAL REVENUE		**$22,878**	**$22,504**	**$23,065**	**$23,329**	**$21,210**	**$20,606**	**$19,404**	**$18,587**
COST									
Monthly cost (MHE and Manpower)		$ 4,317	$ 4,317	$ 4,317	$ 4,317	$ 4,317	$ 4,317	$ 4,317	$ 4,317
Variable cost	34%	$7,778	$7,651	$7,842	$7,932	$7,211	$7,006	$6,597	$6,319
Over time cost		$ 1,777	$ 1,600	$ 1,300	$ 1,481	$ 819	$ 663		
Send pallets to other warehouse		$ 1,500	$ 1,500	$ 3,000	$ 4,500	$ 1,500	$ 1,500		
TOTAL COST		**$ 15,372**	**$ 15,068**	**$ 16,459**	**$ 18,230**	**$ 13,846**	**$ 13,486**	**$ 10,914**	**$ 10,636**
PROFIT		**$ 7,505**	**$ 7,436**	**$ 6,607**	**$ 5,099**	**$ 7,363**	**$ 7,120**	**$ 8,490**	**$ 7,951**

Table 22 profit results during high season period

5.2.5 High season special rate

The company could establish a strategy during the high season. That is, to charge an extra fee to compensate the extra cost of the operations. Looking at Table 22 and taking the periods three, six and seven as references, we can see that there is a significant loss in profit attached to the warehouse occupancy. Table 23 shows how much money the site is losing because of the extra volume and how much the rates should be in order to recover the money. Whenever the warehouse occupancy surpasses the 88.7% (or 90%) the company should increase the rates by a 10% and whenever it surpasses the 97.1% (or 100%) the rates should be increased by around 12 to 15%.

Period	Warehouse occupancy	PROFIT	difference	Extra charge %
3	106.6%	$6,607	$ 1,883	12%
6	97.1%	$7,120	$ 1,370	10%
7	88.7%	$8,490	$ -	0%

Table 23 Extra charge for the high season

Chapter 6. Conclusions

Considering the obtained results of this thesis, we recommend the company to always keep the warehouse occupancy between 83.5% and 87.7%. This conclusion is based on the results of the simulation model built in Arena. The model takes into consideration the distribution of the inbounds and outbound operations for one customer and the workforce operations of a warehouse in a 100% full pallet pick environment with the use of turret truck.

The company may expect a reduction of about 20% in the productivity of the operations during the high season period. This is due to the extra work required to manipulate the products at the upper levels of the warehouse. On the other side, during the low season, the machine is idle 50% of the time.

There are some strategies that the company could implement for the high and low season. During the high season, it is often seen sites paying for over time or penalty fees. On the other hand, during the low season period, the company has idle resources and low profit because of the low volumes.

During the high season, an extra charge per occupancy level could be charged. In this way, additional customers may be served without having a negative impact on the profits of the company. It is suggested an increase of the rates of 10% after a 90% of occupancy and 15% increase of the rate after a 100% of occupancy.

The company may also adopt a similar strategy for the low season period. When the occupancy level is lower than 80%, it could reduce the rates to attract small customers or/and more volume from existing customers. This can potentially increase the profits during the low season periods.

The obtained results also indicate that the use of an extra resource (i.e., worker and turret) is not recommended. The extra cost attached to the extra turret and employee is too high as compared to the potential increase in revenues. It seems to be a better option to either pay overtime or refuse products, before considering the addition of an extra resource.

The current simulation model has been customized for the particular characteristic of one precise customer and the capacity of one particular warehouse. If the model wants to be used for the study of other customers, it is necessary to modify the developed model. On the other hand, everything that is related to the workforce can be applied for future studies where turret truck in a narrow aisle environment is used.

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Annex A

Element:	Retrieve and Putaway Scanner from the Holster		
Method:	BasicMOST		
Description:	Retrieve the RF Scanner from the Holster and place it back after use		
Element starts:	Operator is on the machine		
Element ends:	Operator has the RF Scanner on his/her hand		
Time:	80.0	TMU	
	0.0480	**min.**	
	2.9	sec.	
MOST Multiplicator:			10

Sequence #	Seq Type	Description & Sequence	Subtotal
1	G	Retrieve the RF Scanner from the Holster	40
		A 1 B 0 G 3 A 1 B 0 P	
1	G	Place the RF Scanner in the holster	40
		A 0 B 0 G 0 A 1 B 0 P	

Annex B

Turret Truck Calibration Analysis

Scenarios	Overall Averages
Long Travel Empty Load	**0.405743**
Long Travel Light Load	**0.402681**
Long Travel Heavy Load	**0.412901**
Empty Load Lift	**2.000742**
Empty Load Drop	**2.253776**
Light Load Lift	**2.185387**
Light Load Drop	**2.211742**
Heavy Load Lift	**2.329661**
Heavy Load Drop	**2.154322**

Machine #	**Long Travel Empty Load**	**Long Travel Light Load**	**Long Travel Heavy Load**
1	0.421216	0.404803	0.405636
2	0.388034	0.395531	0.399840
3	0.407977	0.407710	0.433226
Machine #	**Empty Load Lift**	**Light Load Lift**	**Heavy Load Lift**
1	1.962899	2.101714	2.150710
2	1.897982	2.122733	2.141246
3	2.141345	2.331714	2.697027
Machine #	**Empty Load Drop**	**Light Load Drop**	**Heavy Load Drop**
1	2.241016	2.175062	2.203009
2	2.084409	2.191474	2.108937
3	2.435905	2.268689	2.151020

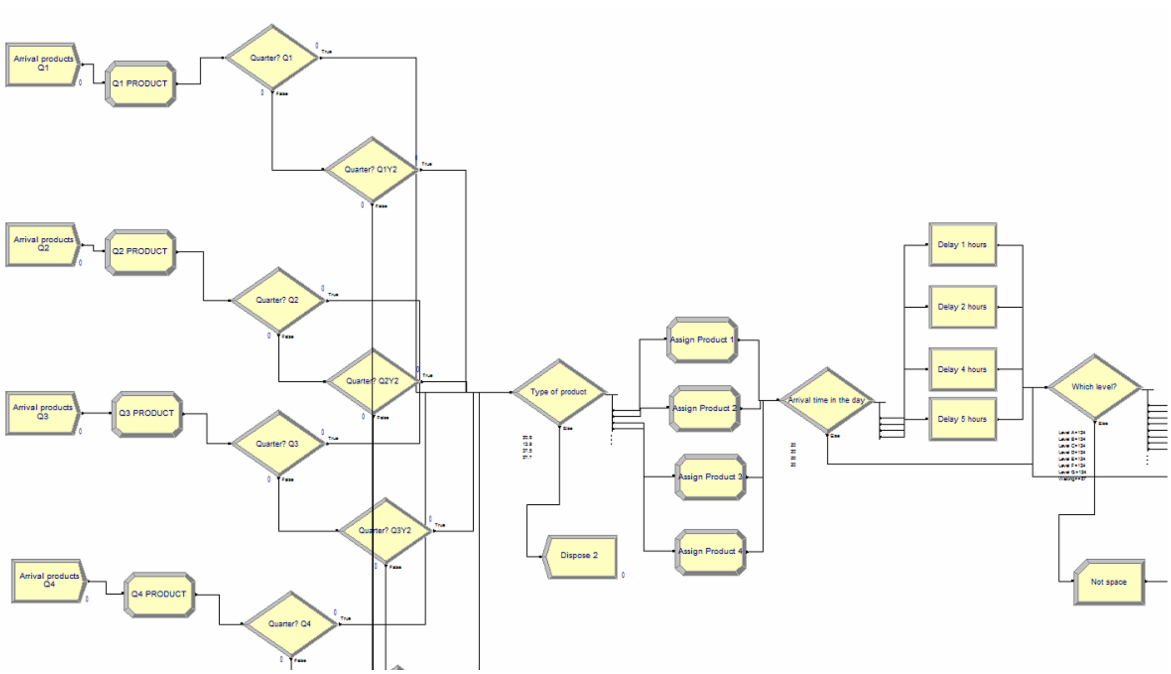
Annex C

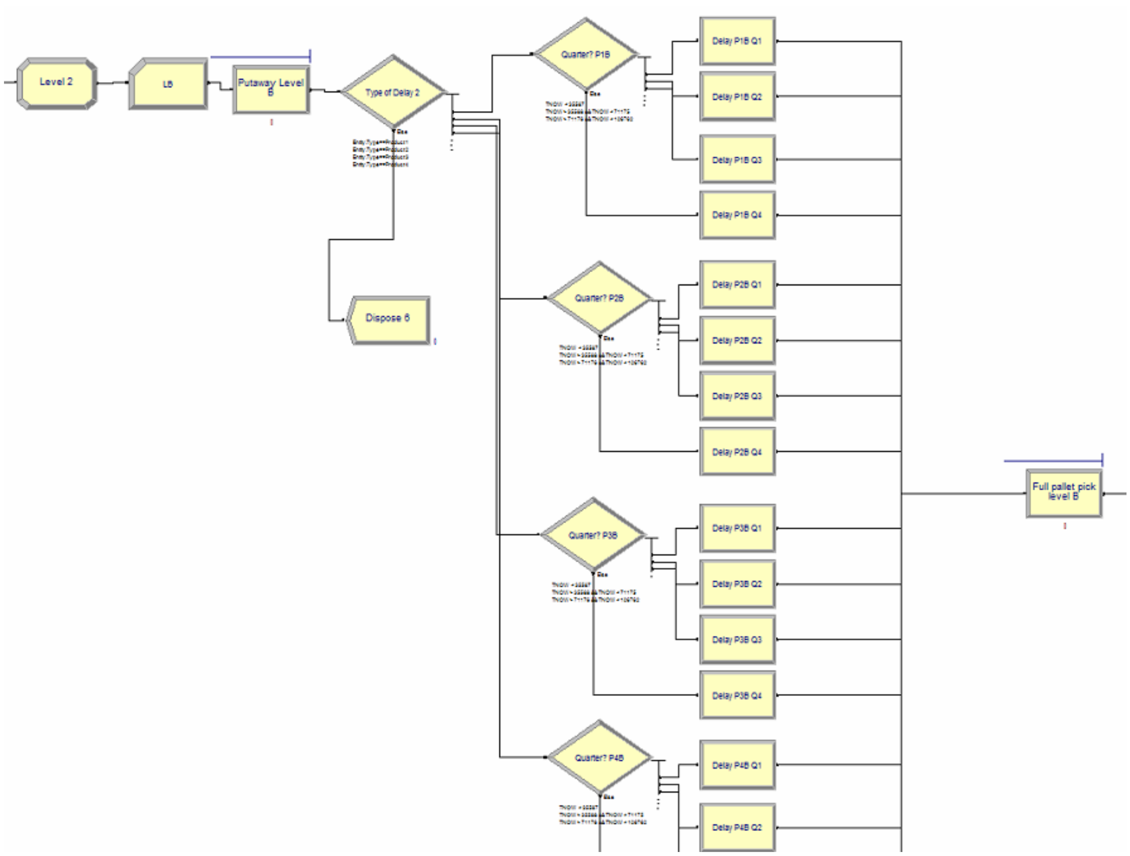
	Insert SD (Level 1)	Insert SD (Level 2)	Insert SD (Level 3)	Insert SD (Level 4)	Insert SD (Level 5)	
Average	**10.7833**	**13.0590**	**12.3836**	**12.9590**	**14.6668**	
LCL	8.200769	9.82	10.41	10.49	10.95	
UCL	13.37	16.30	14.36	15.4262	18.38	
Relative Error %	**4.61%**	**3.92%**	**4.81%**	**4.26%**	**3.95%**	
Number Of observations	27	40	11	20	41	
Min	8.82	9.81	10.61	10.68	10.77	
Max	14.27	16.94	13.97	15.14	18.10	
Std Dev	1.317635	1.65	1.01	1.26	1.89	

	Retrieve SD (Level 1)	Retrieve SD (Level 2)	Retrieve SD (Level 3)	Retrieve SD (Level 4)	Retrieve SD (Level 5)	Retrieve SD (Level 6)
Average	**11.1910**	**11.5400**	**11.6700**	**11.7907**	**11.9014**	**13.5047**
LCL	9.510350	9.51	9.14	9.79	10.46	11.045825
UCL	12.87	13.57	14.20	13.79	13.3460	15.96
Relative Error %	**3.36%**	**4.55%**	**4.85%**	**4.54%**	**4.59%**	**4.70%**
Number Of observations	20	15	20	14	7	15
Min	9.40	10.16	8.90	10.28	10.91	11.10
Max	12.92	13.60	13.90	13.38	12.73	15.60
Std Dev	0.857474	1.04	1.29	1.02	0.74	1.254511

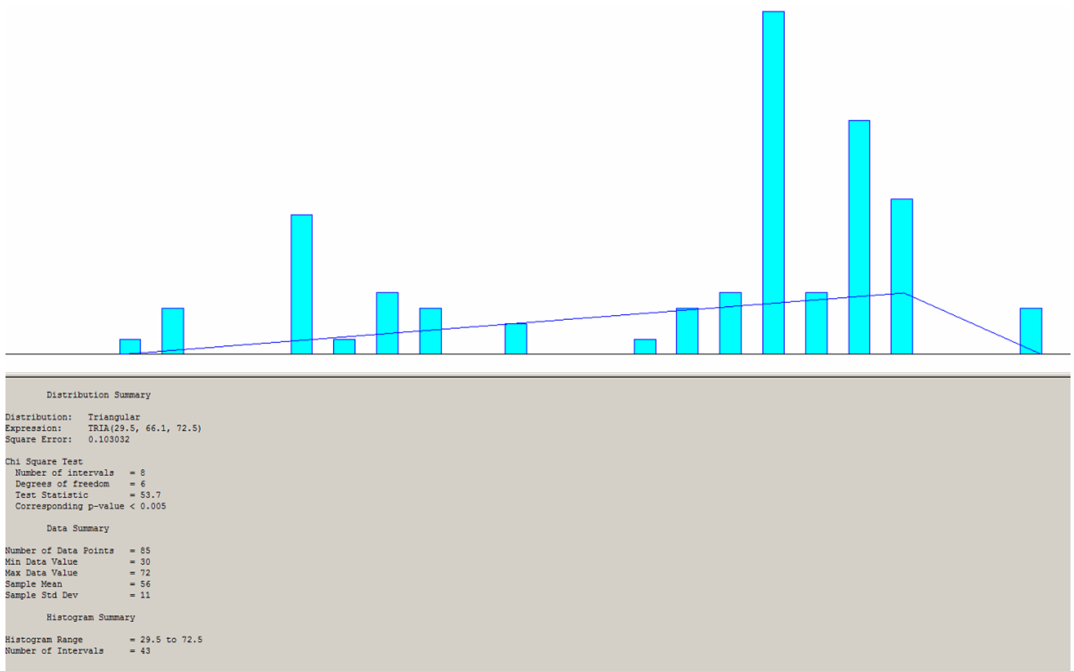
	TITL (-)	TAFL (-)	PPF (-)	PUP (-)	C90 (-)	
Average	**4.4752**	**4.6995**	**3.9385**	**4.1771**	**4.9296**	
LCL	2.450736	2.71	2.42	2.44	2.95	
UCL	6.50	6.69	5.45	5.91	6.9056	
Relative Error %	**4.69%**	**4.44%**	**4.97%**	**4.90%**	**4.60%**	
Number Of observations	93	91	60	72	76	
Min	2.79	2.74	2.58	2.54	3.33	
Max	6.90	6.74	5.97	5.96	7.77	
Std Dev	1.032870	1.02	0.77	0.89	1.01	

Annex D

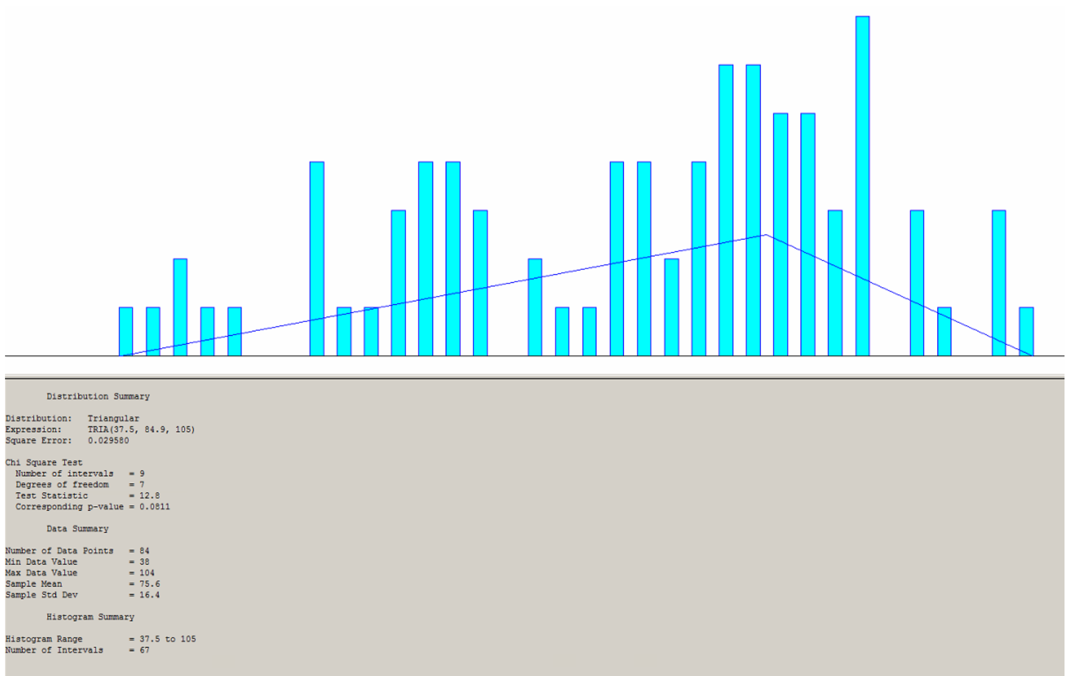

Arrival products Q1
Q1 PRODUCT
Quarter? Q1
Quarter? Q1Y2
Arrival products Q2
Q2 PRODUCT
Quarter? Q2
Quarter? Q2Y2
Arrival products Q3
Q3 PRODUCT
Quarter? Q3
Quarter? Q3Y2
Arrival products Q4
Q4 PRODUCT
Quarter? Q4
Type of product
Dispose 2
Assign Product 1
Assign Product 2
Assign Product 3
Assign Product 4
Arrival time in the day
Delay 1 hours
Delay 2 hours
Delay 4 hours
Delay 5 hours
Which level?
Not space


Level 2
LB
Putaway Level B
Type of Delay 2
Dispose 6
Quarter? P1B
Delay P1B Q1
Delay P1B Q2
Delay P1B Q3
Delay P1B Q4
Quarter? P2B
Delay P2B Q1
Delay P2B Q2
Delay P2B Q3
Delay P2B Q4
Quarter? P3B
Delay P3B Q1
Delay P3B Q2
Delay P3B Q3
Delay P3B Q4
Quarter? P4B
Delay P4B Q1
Delay P4B Q2
Full pallet pick level B

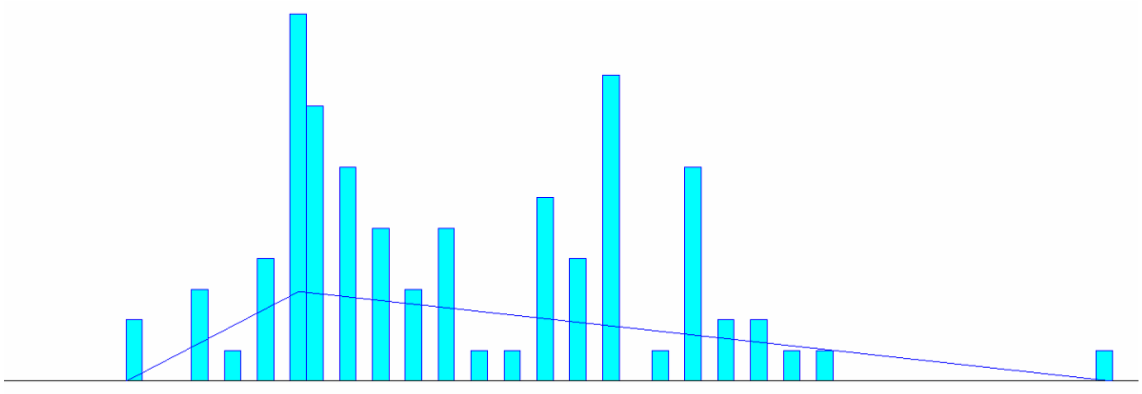
Annex E



Inbound distribution for Q1

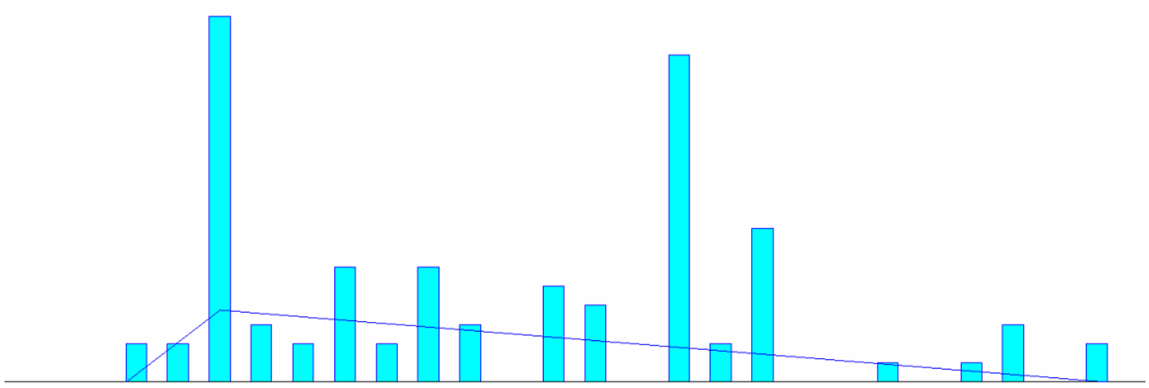


Inbound distribution for Q2



```
        Distribution Summary

Distribution:   Triangular
Expression:     TRIA(64.5, 75, 125)
Square Error:   0.047727

Chi Square Test
  Number of intervals   = 9
  Degrees of freedom    = 7
  Test Statistic        = 46.8
  Corresponding p-value < 0.005

        Data Summary

Number of Data Points   = 88
Min Data Value          = 65
Max Data Value          = 124
Sample Mean             = 84.7
Sample Std Dev          = 11.2

        Histogram Summary

Histogram Range         = 64.5 to 125
Number of Intervals     = 60
```

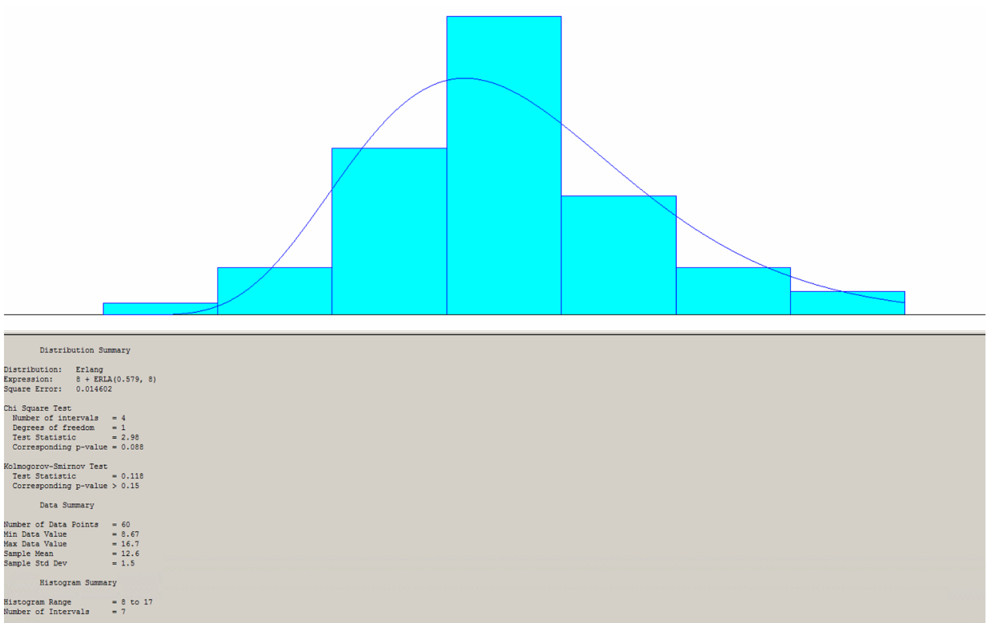
Inbound distribution for Q3



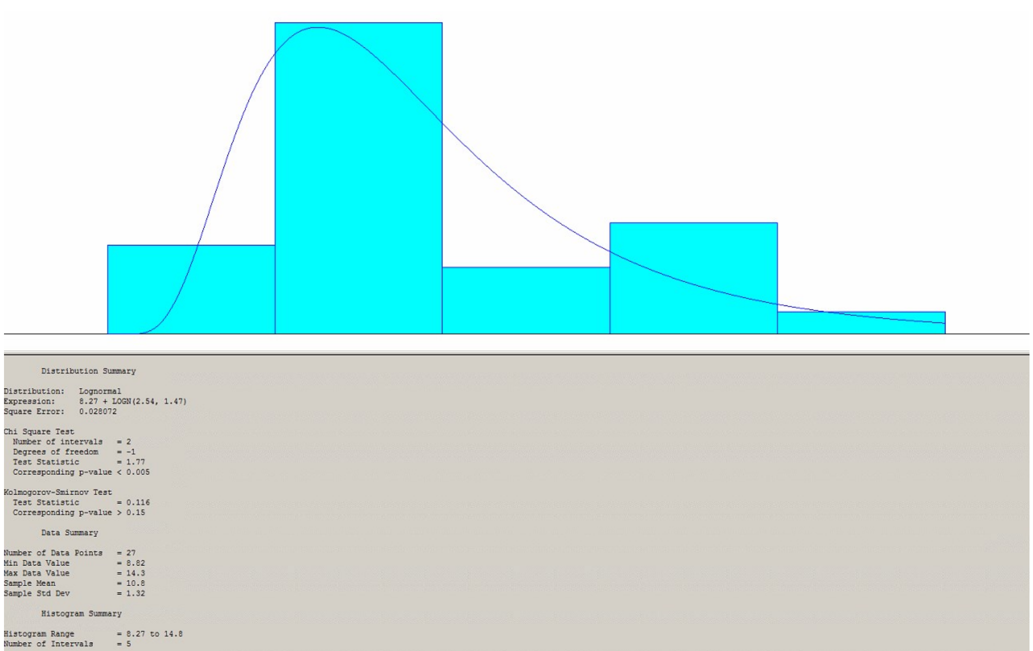
```
        Distribution Summary

Distribution:   Triangular
Expression:     TRIA(33.5, 38, 80.5)
Square Error:   0.087541

Chi Square Test
  Number of intervals   = 8
  Degrees of freedom    = 6
  Test Statistic        = 42.2
  Corresponding p-value < 0.005

        Data Summary

Number of Data Points   = 88
Min Data Value          = 34
Max Data Value          = 80
Sample Mean             = 51.6
Sample Std Dev          = 12.1

        Histogram Summary

Histogram Range         = 33.5 to 80.5
Number of Intervals     = 47
```

Inbound distribution for Q4

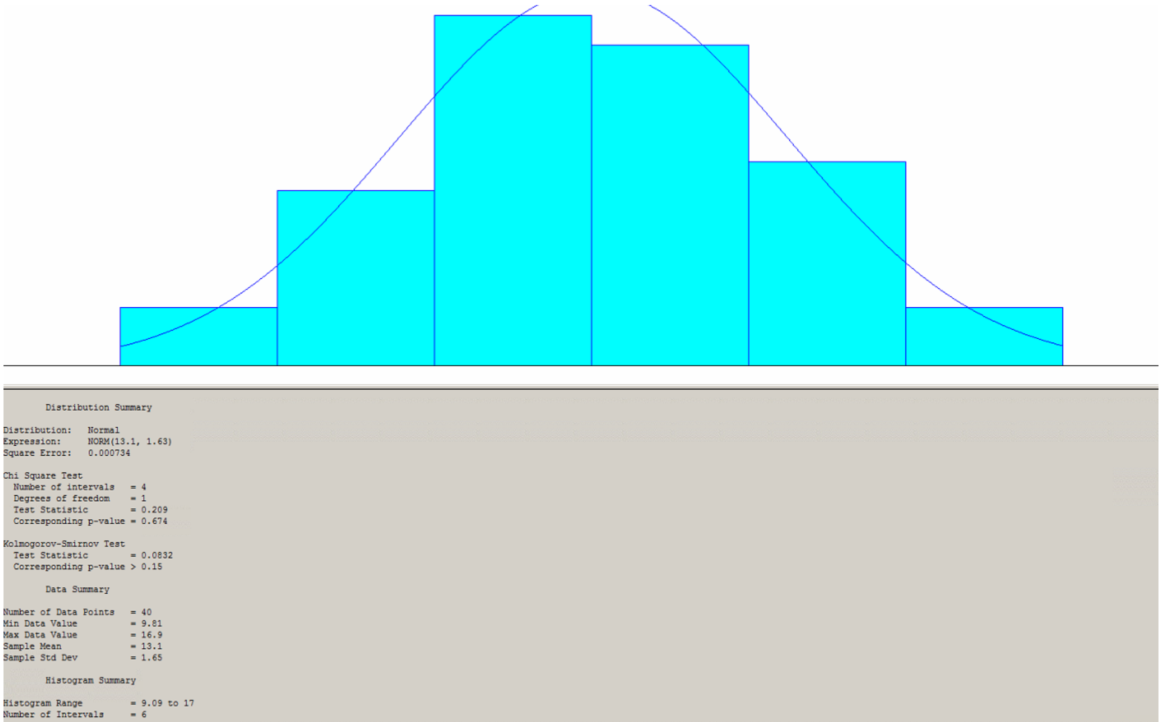
Annex F



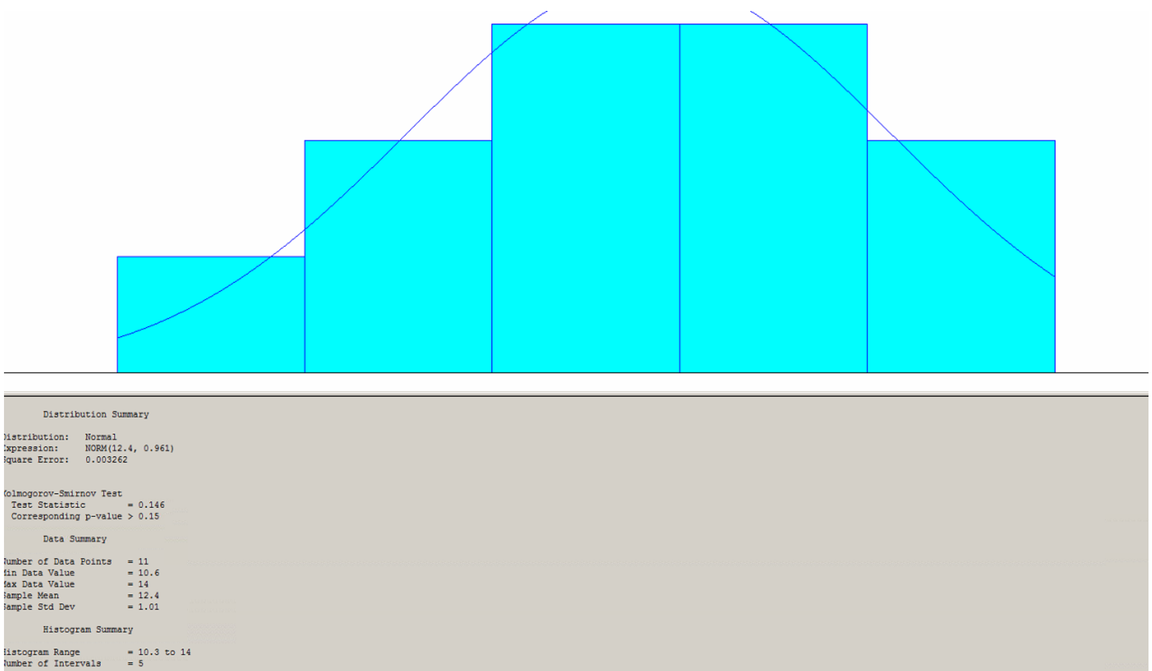
Machine general movements



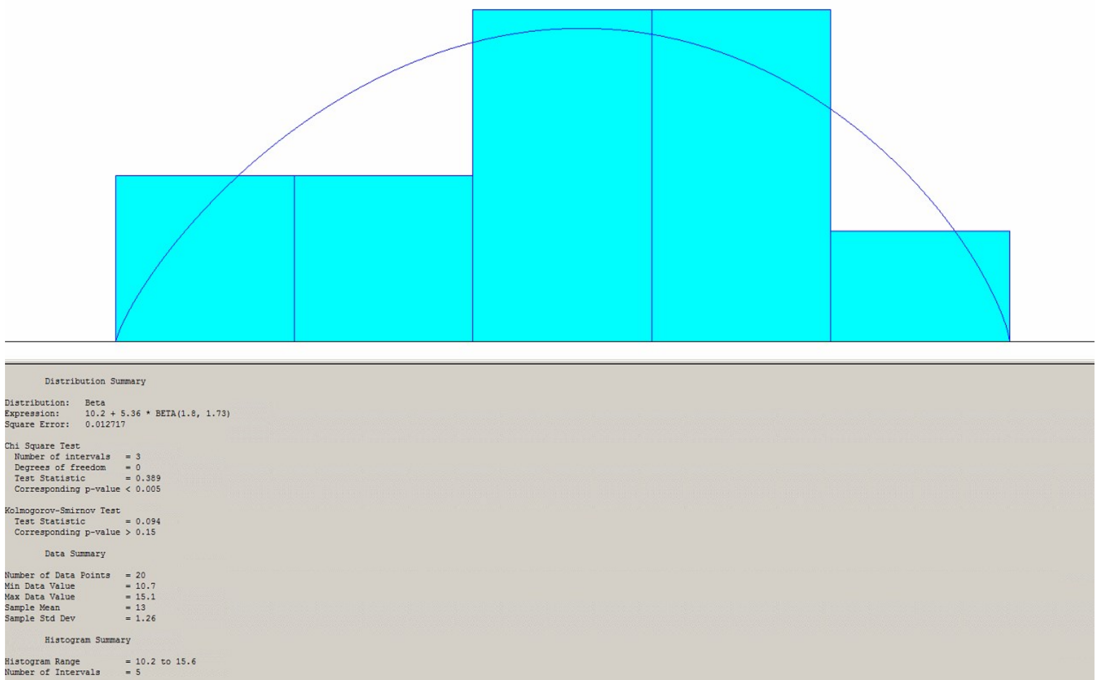
Insert time level A



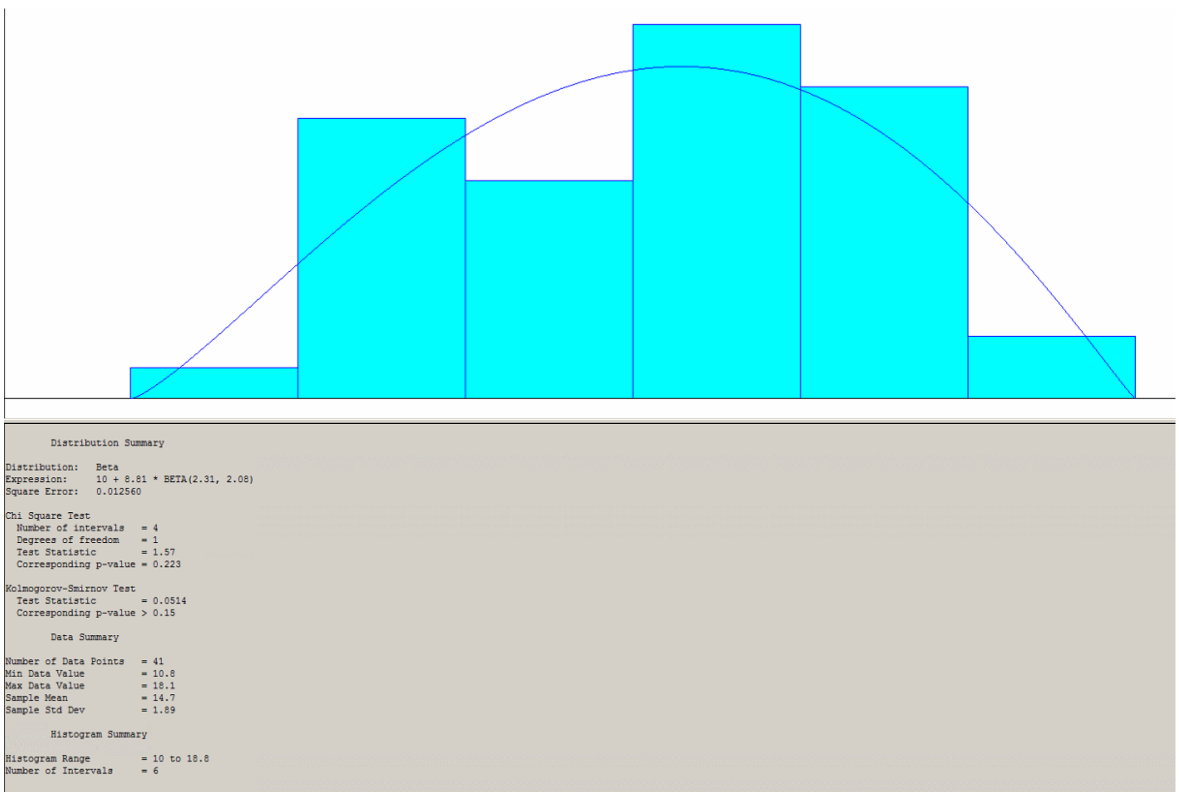
Insert time level B



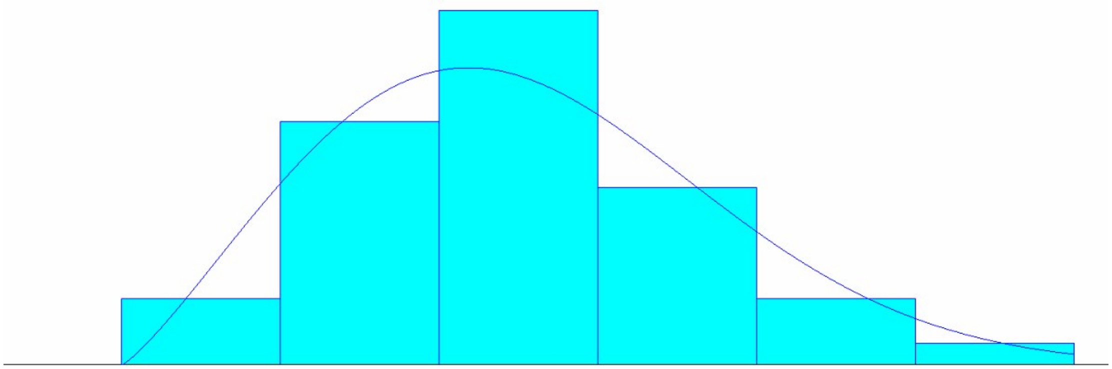
Insert time level C



Insert time level D



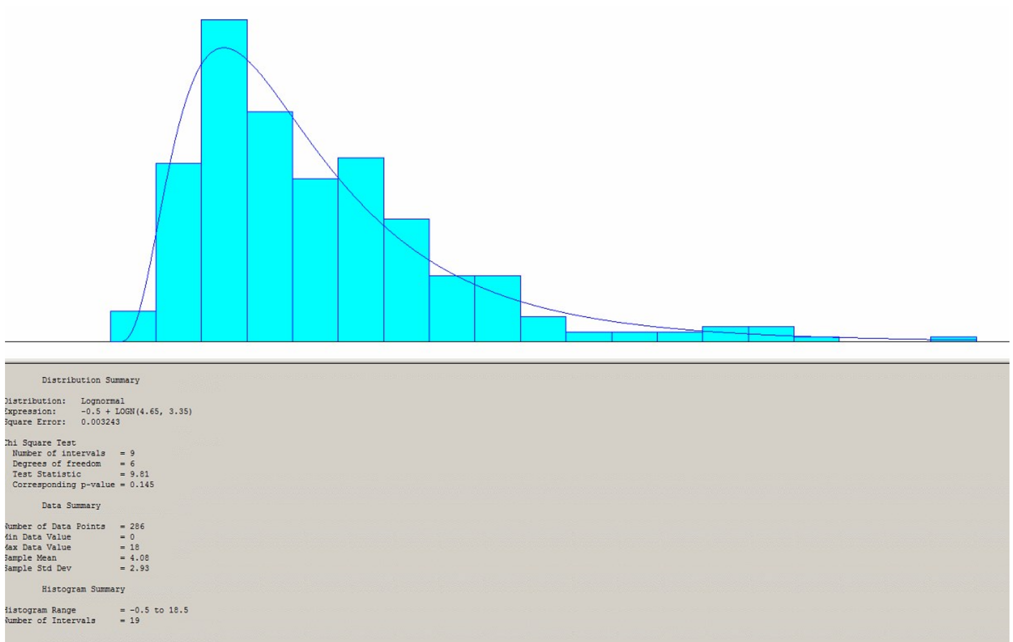
Insert time level E



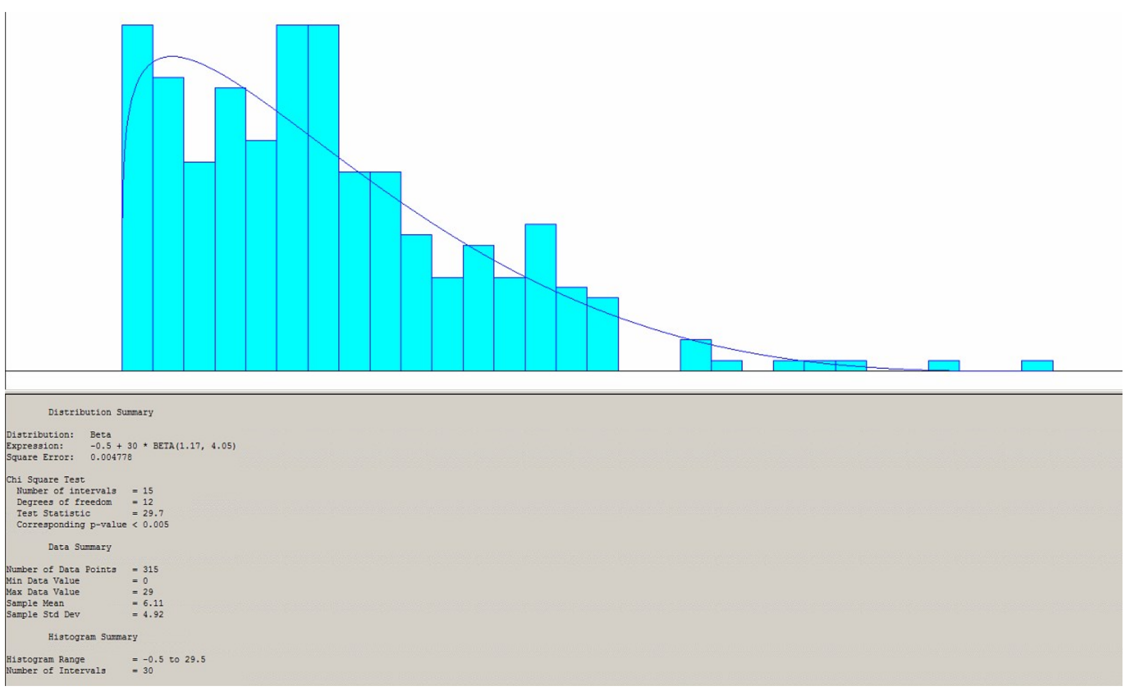
```
        Distribution Summary

Distribution:   Weibull
Expression:     12 + WEIB(7.18, 2.21)
Square Error:   0.006948

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 0
  Test Statistic        = 1.15
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0865
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 42
Min Data Value          = 12.4
Max Data Value          = 26.2
Sample Mean             = 18.4
Sample Std Dev          = 3.02

        Histogram Summary

Histogram Range         = 12 to 27
Number of Intervals     = 6
```

Insert time level F and G

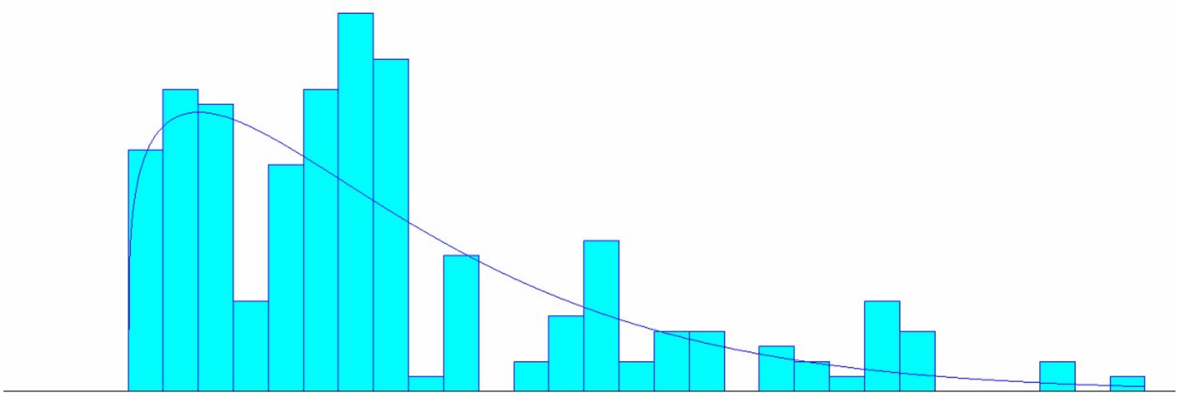
Annex G



Holding time distribution Product 1 Q1

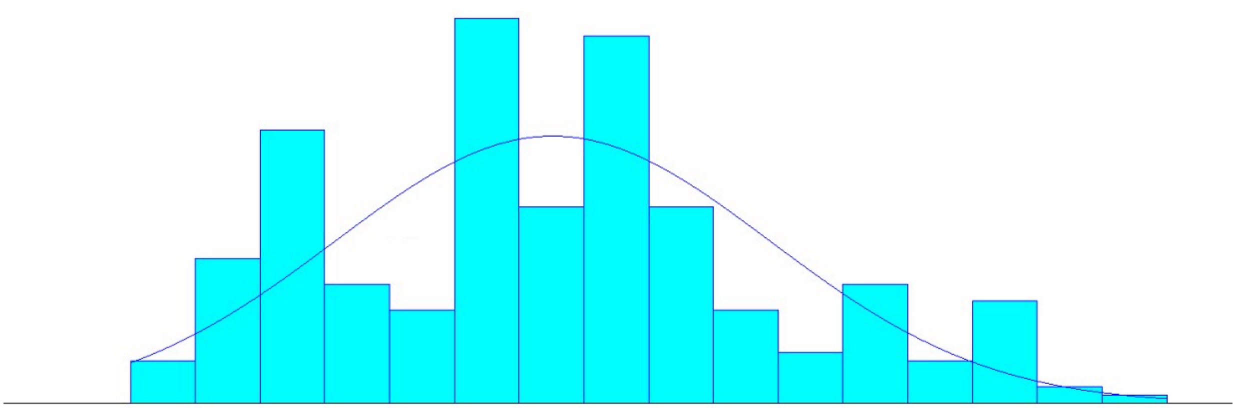


Holding time distribution Product 1 Q2



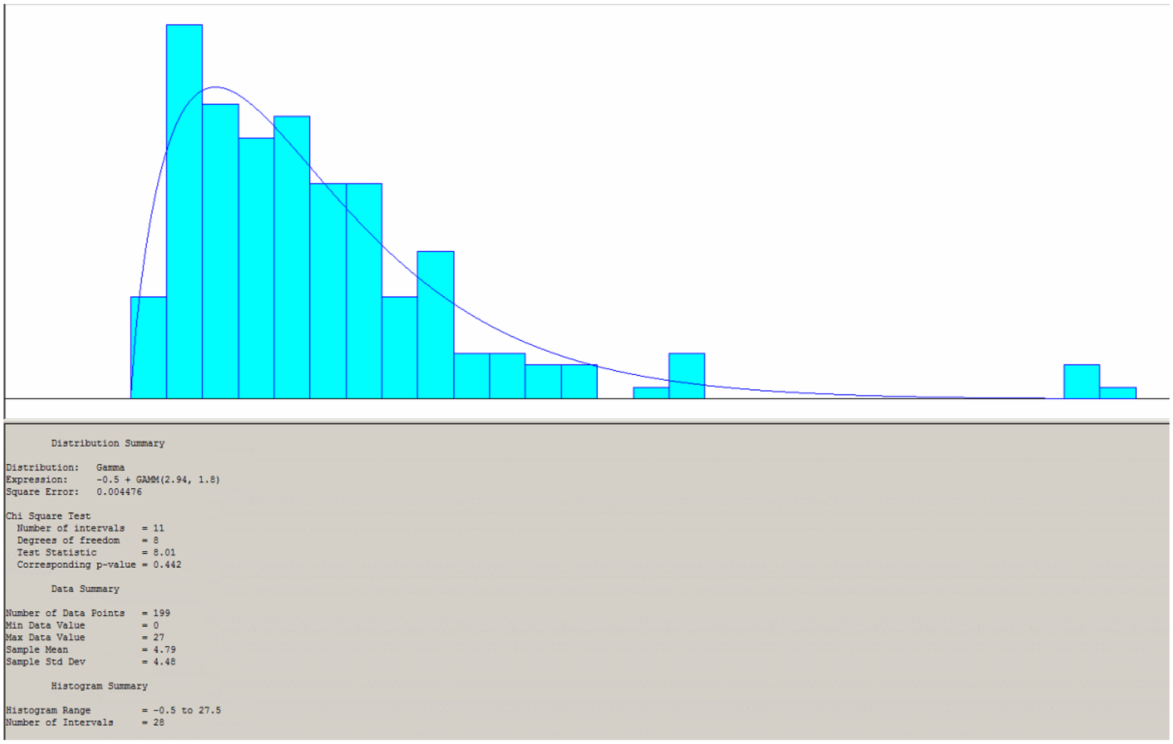
```
Distribution Summary

Distribution:   Weibull
Expression:     0.5 + WEIB(8.05, 1.22)
Square Error:   0.016577

Chi Square Test
  Number of intervals   = 13
  Degrees of freedom    = 10
  Test Statistic        = 45.9
  Corresponding p-value < 0.005

Data Summary

Number of Data Points   = 199
Min Data Value          = 1
Max Data Value          = 29
Sample Mean             = 8.03
Sample Std Dev          = 6.2

Histogram Summary

Histogram Range         = 0.5 to 29.5
Number of Intervals     = 29
```

Holding time distribution Product 1 Q3

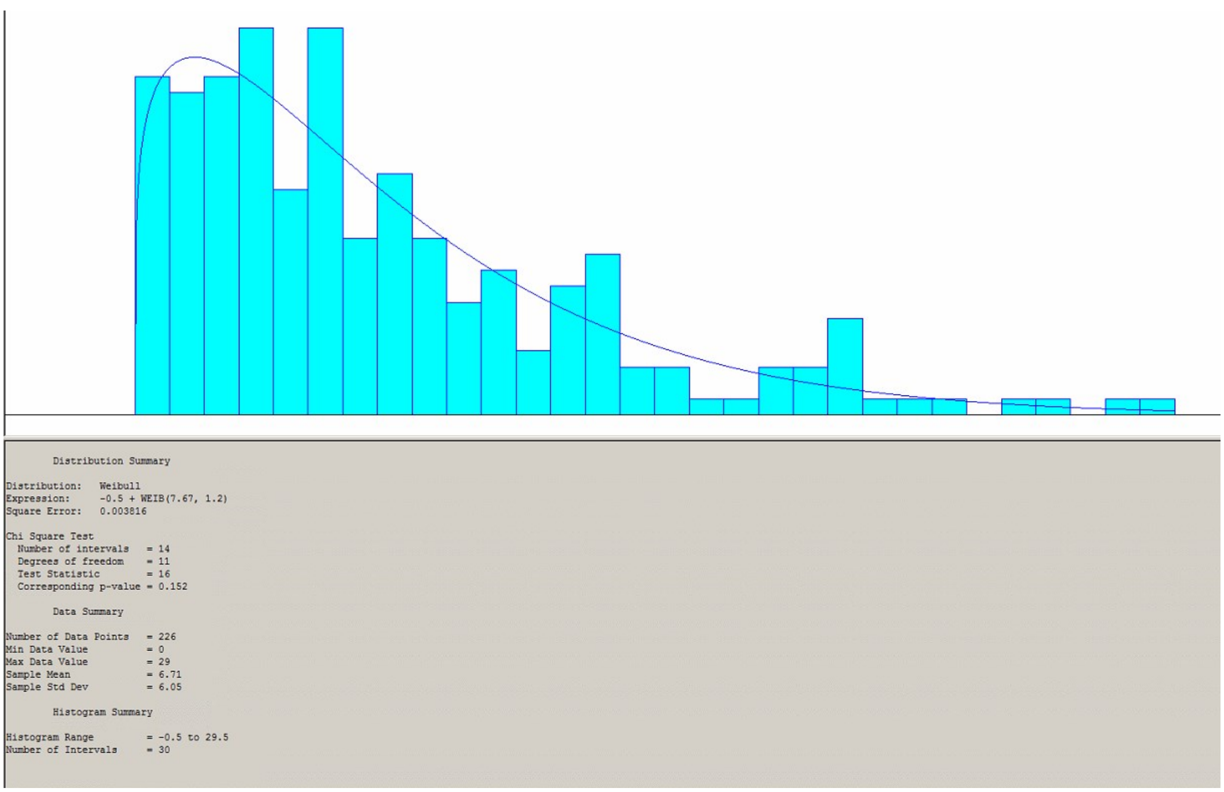


```
Distribution Summary

Distribution:   Normal
Expression:     NORM(6.01, 3.36)
Square Error:   0.019439

Chi Square Test
  Number of intervals   = 12
  Degrees of freedom    = 9
  Test Statistic        = 67
  Corresponding p-value < 0.005

Data Summary

Number of Data Points   = 264
Min Data Value          = 0
Max Data Value          = 15
Sample Mean             = 6.01
Sample Std Dev          = 3.37

Histogram Summary

Histogram Range         = -0.5 to 15.5
Number of Intervals     = 16
```

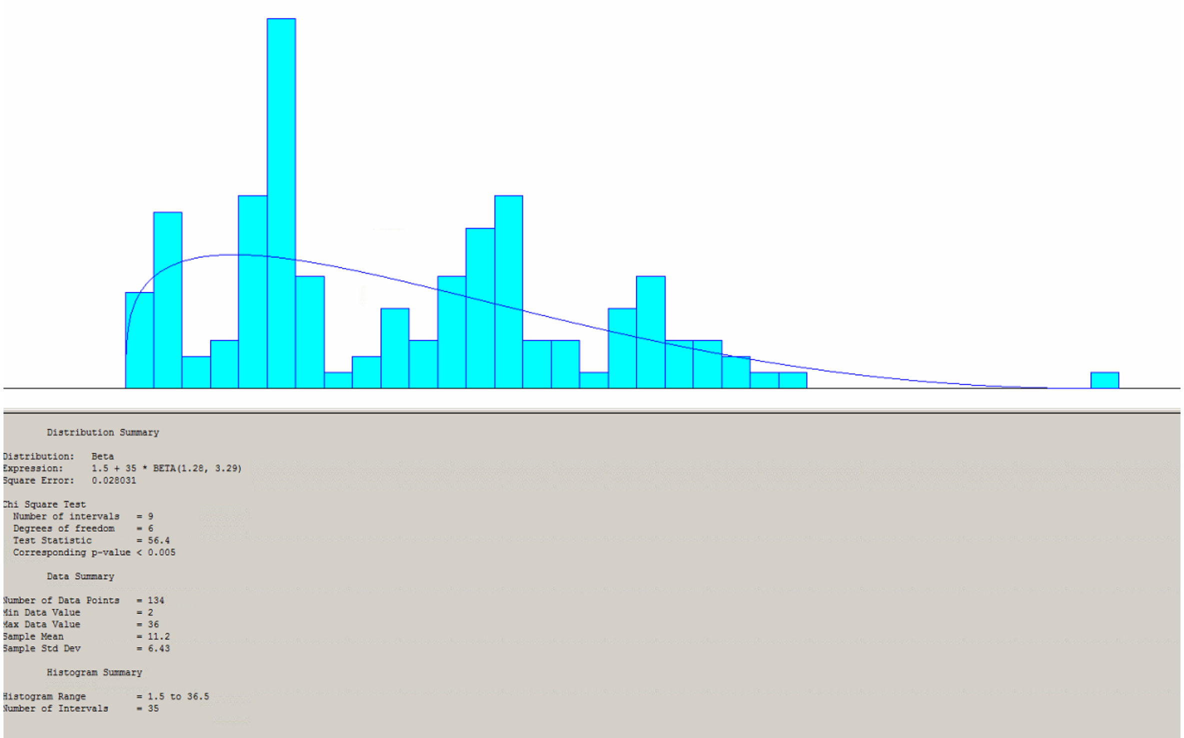
Holding time distribution Product 1 Q4



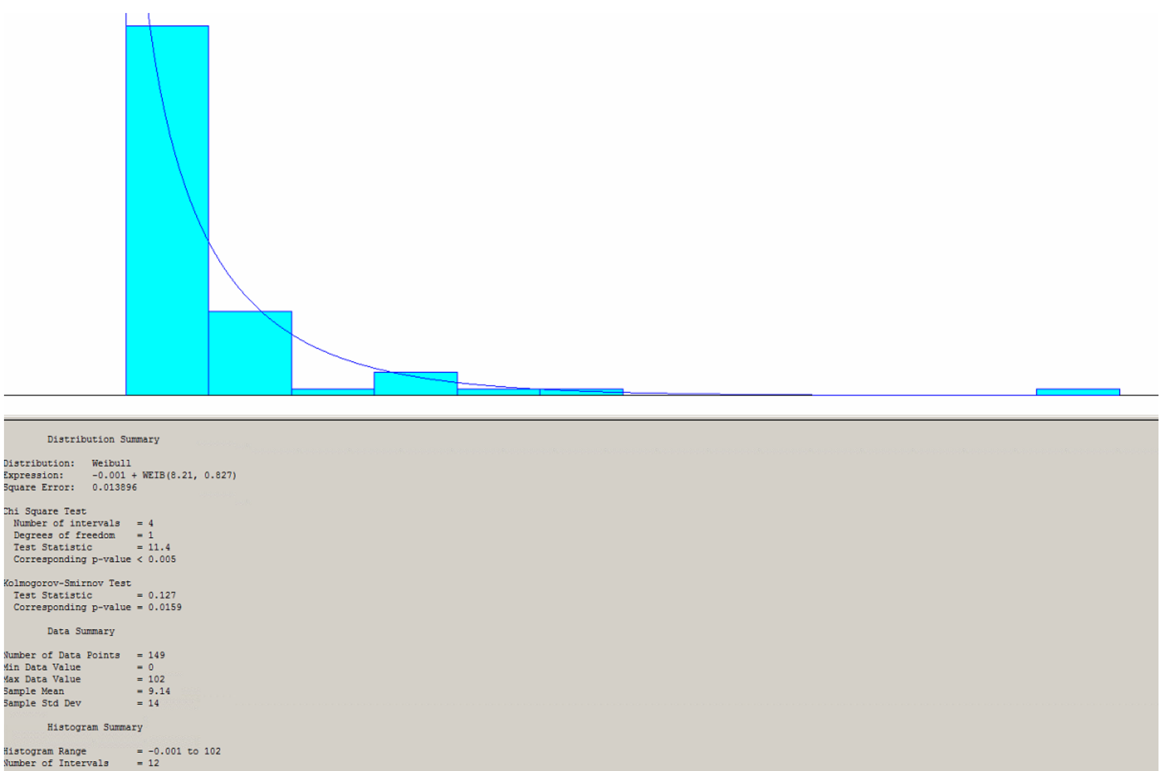
Holding time distribution Product 2 Q1



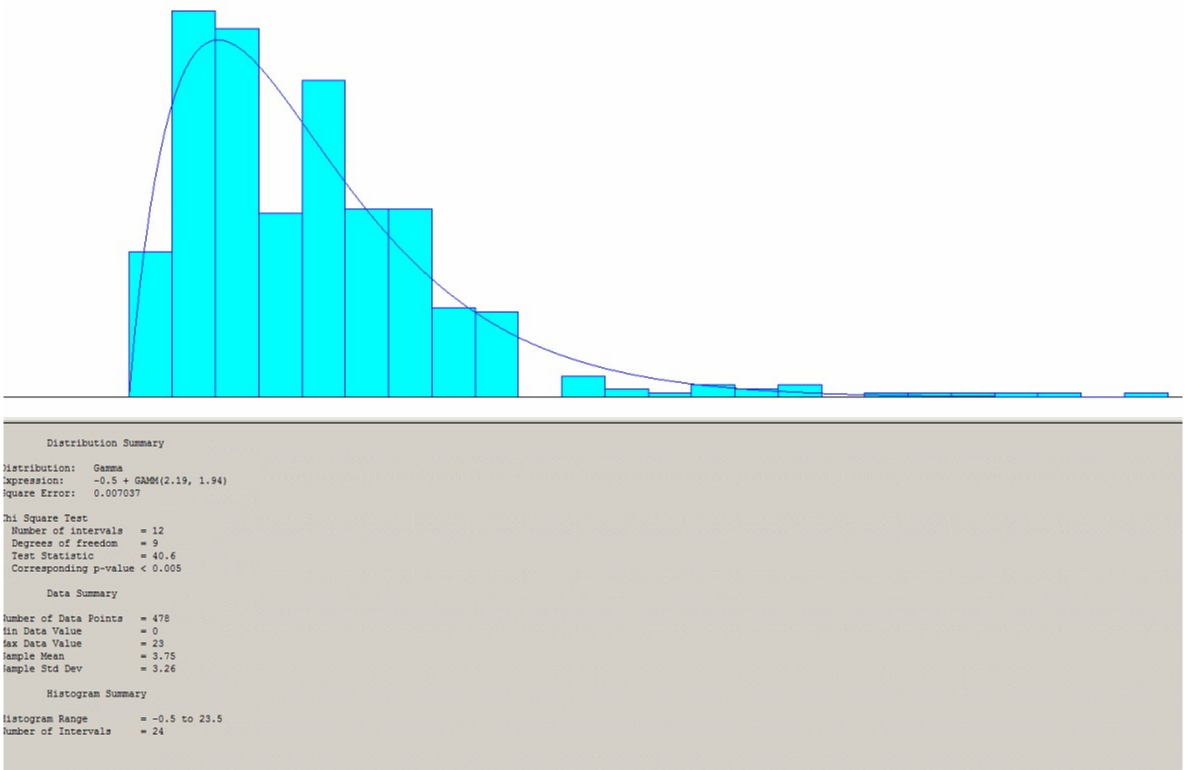
Holding time distribution Product 2 Q2



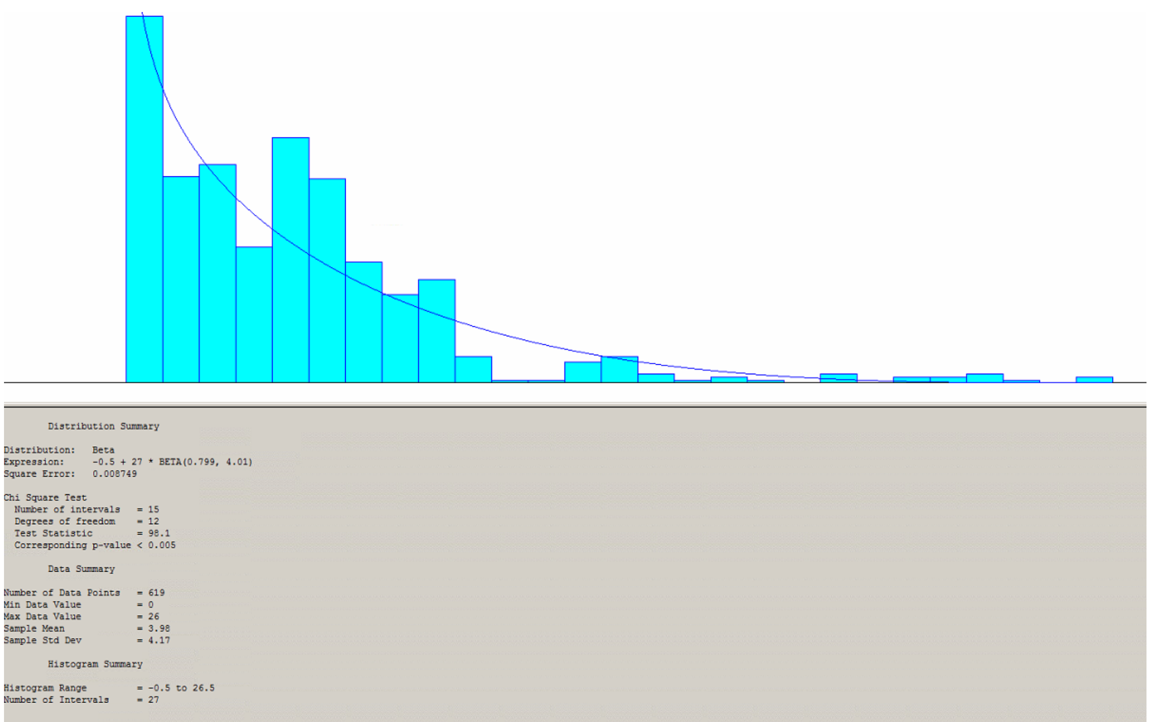
Holding time distribution Product 2 Q3



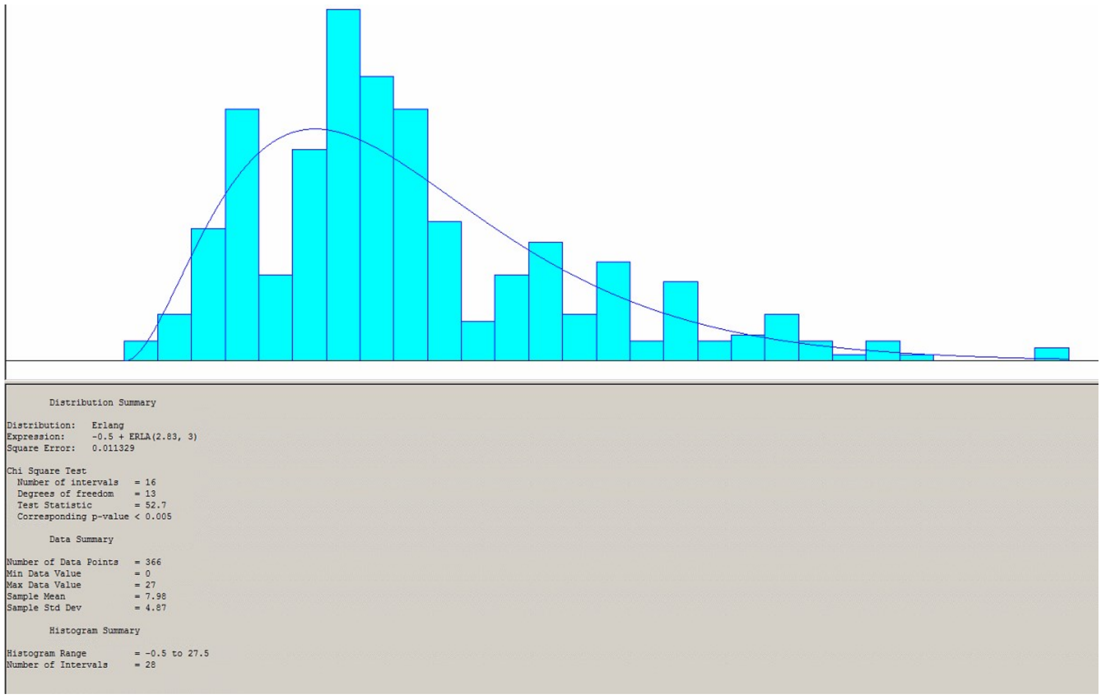
Holding time distribution Product 2 Q4



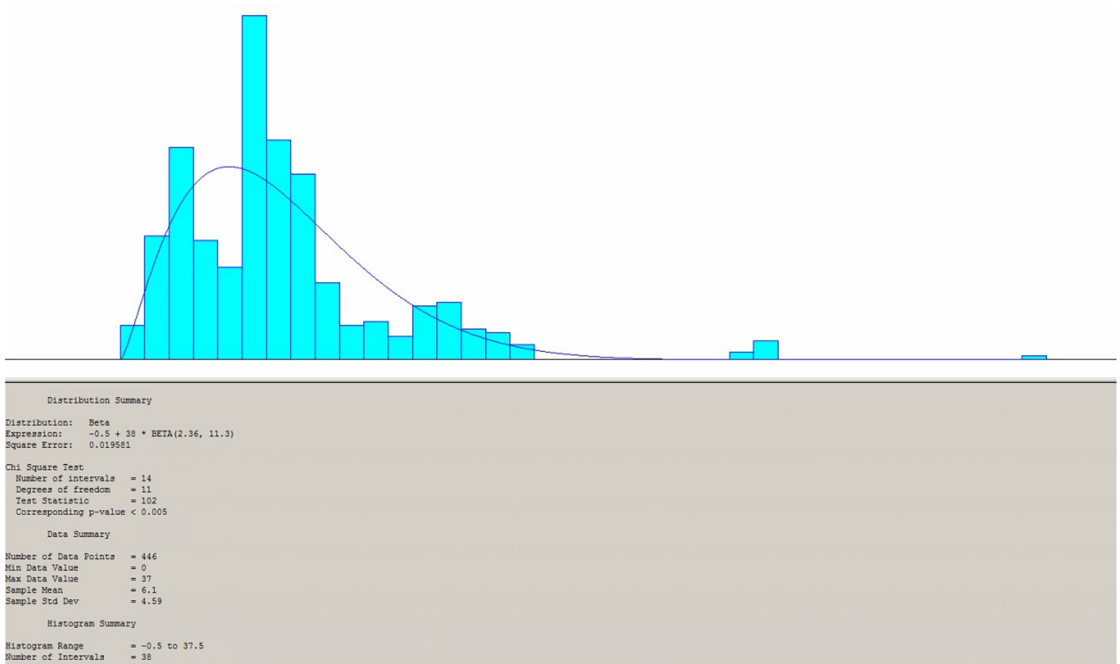
Holding time distribution Product 3 Q1



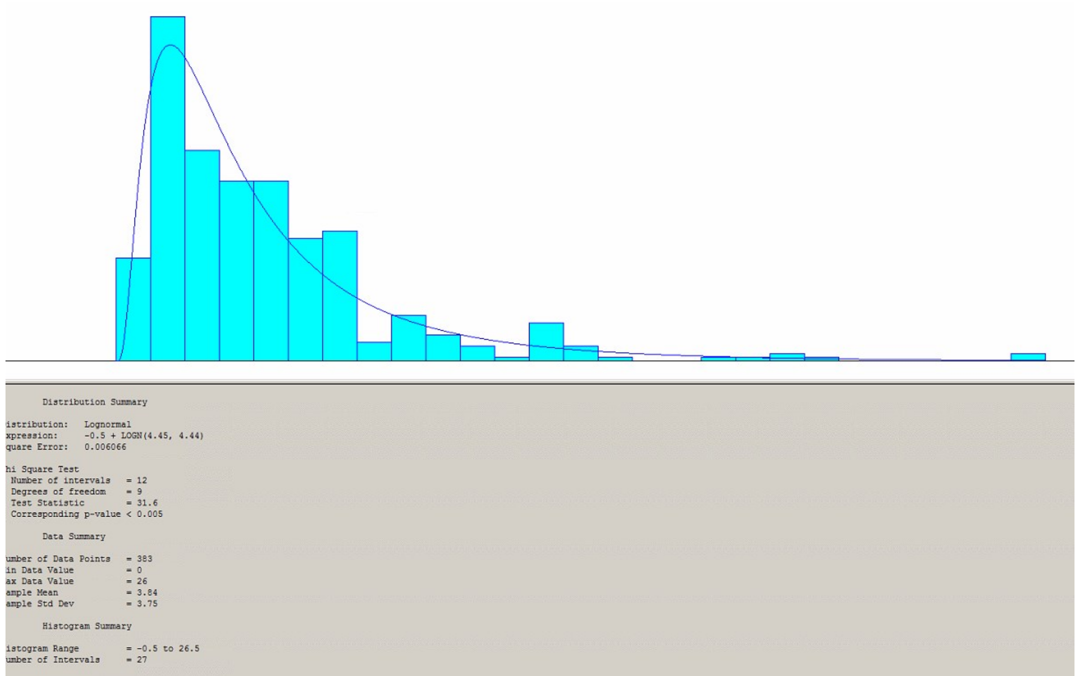
Holding time distribution Product 3 Q2



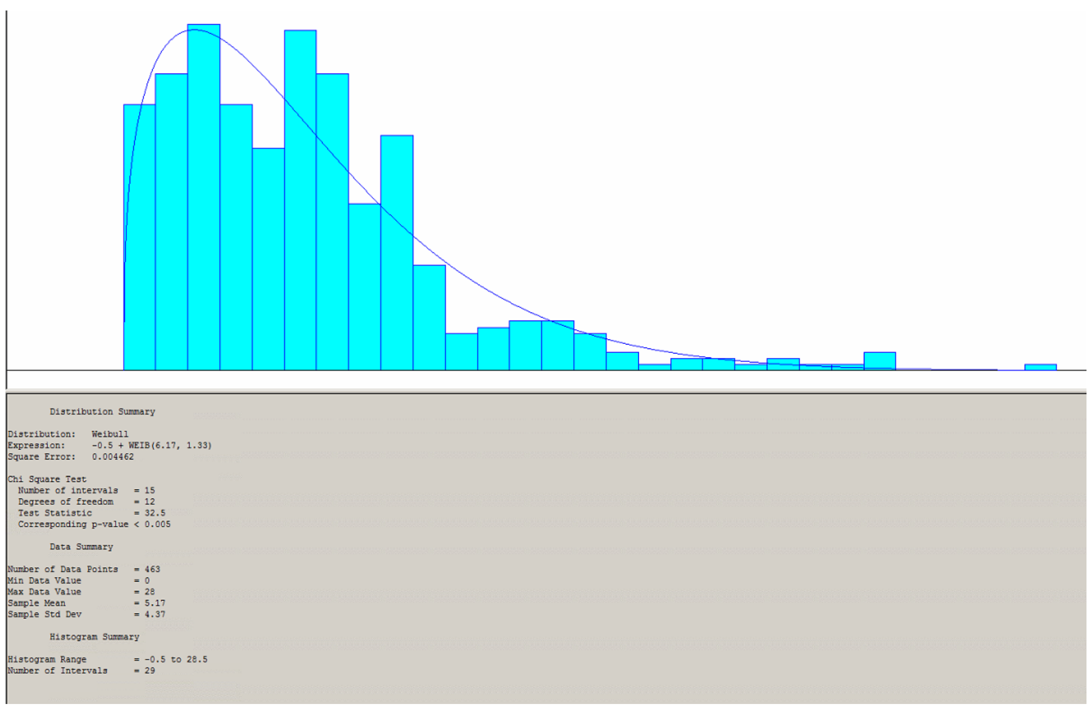
Holding time distribution Product 3 Q3



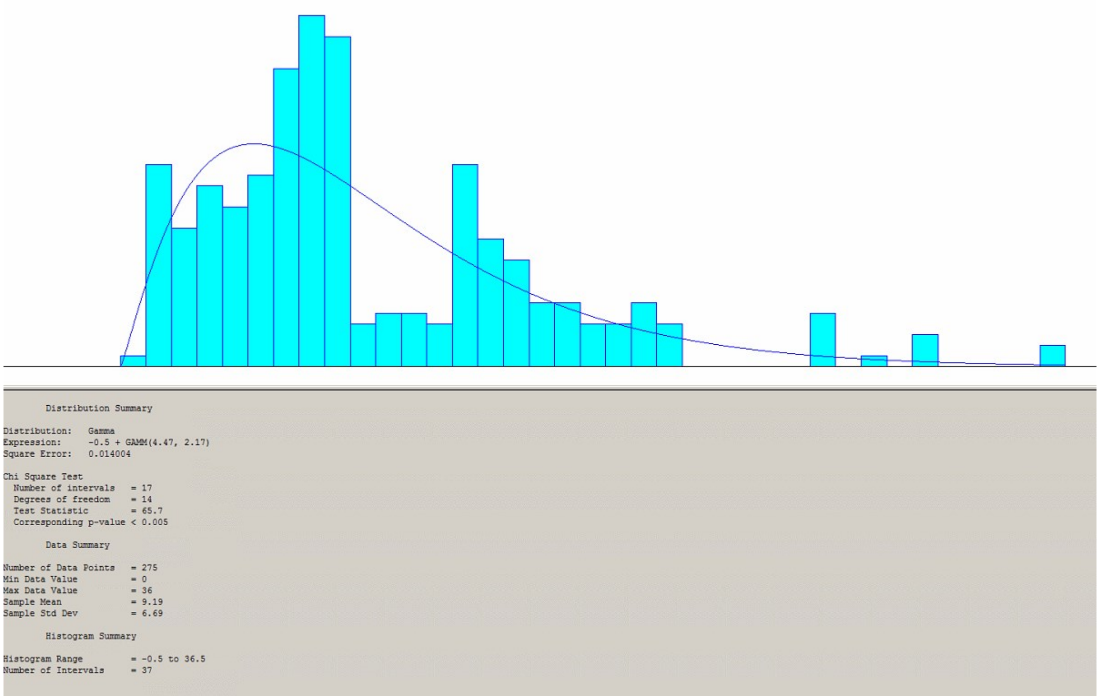
Holding time distribution Product 3 Q4



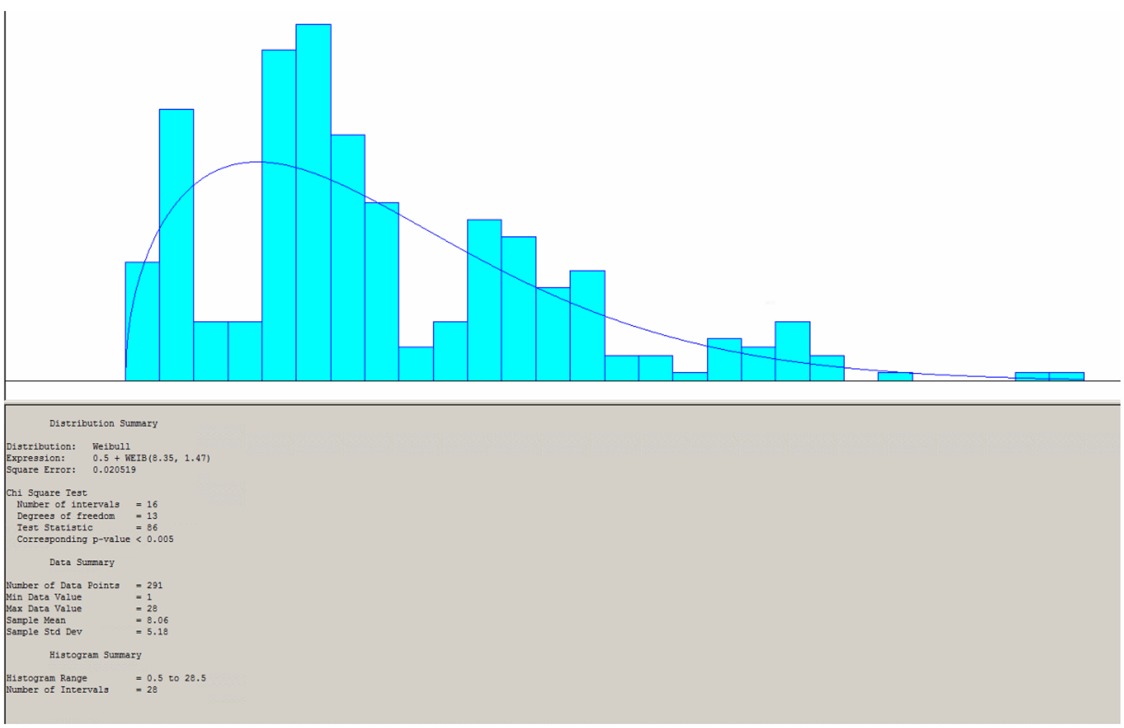
Holding time distribution Product 4 Q1



Holding time distribution Product 4 Q2

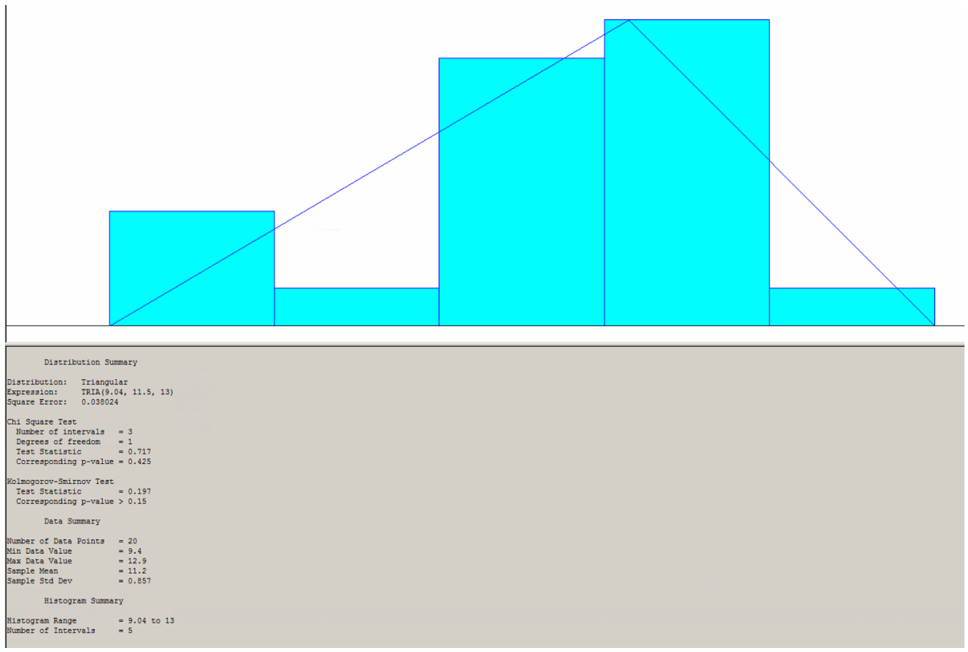


Holding time distribution Product 4 Q3

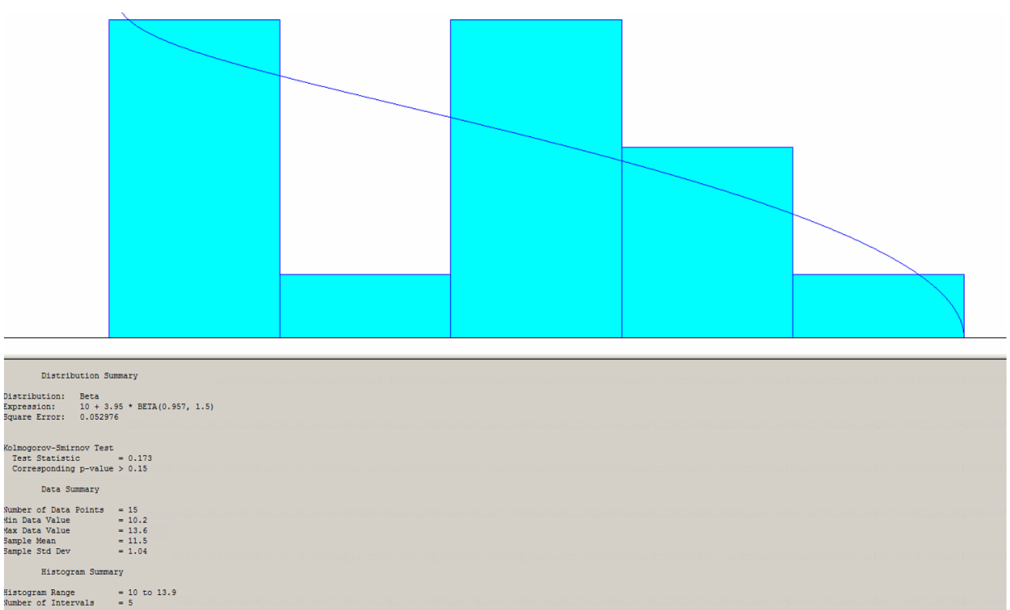


Holding time distribution Product 4 Q4

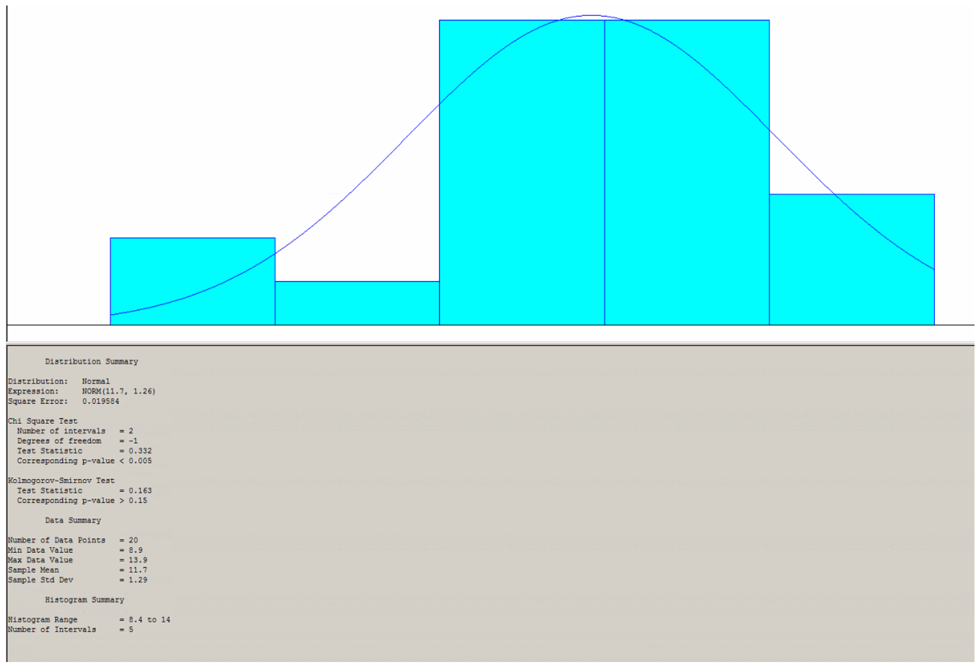
Annex H



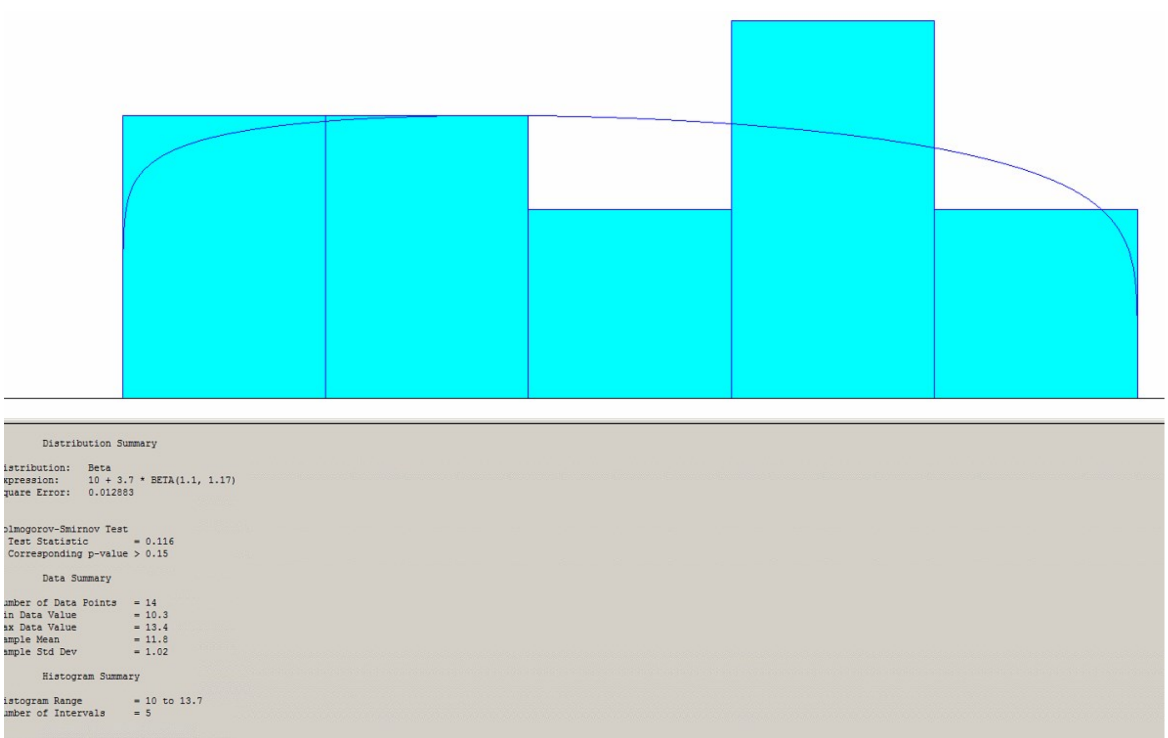
Retrieve time level A



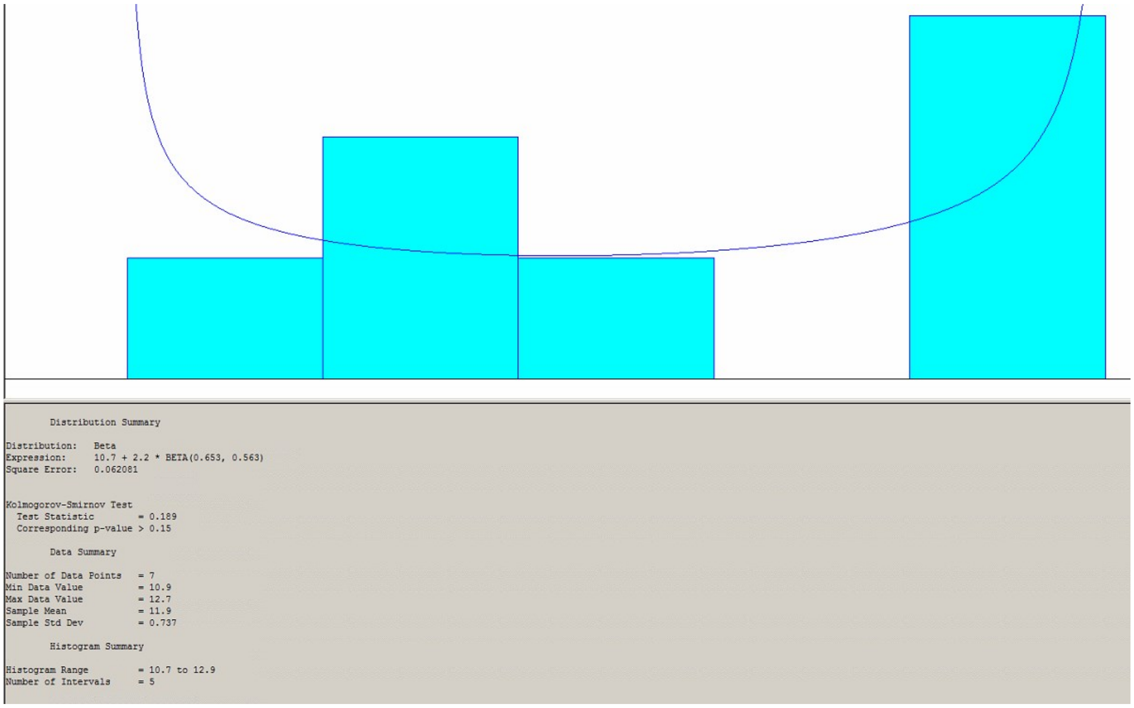
Retrieve time level B



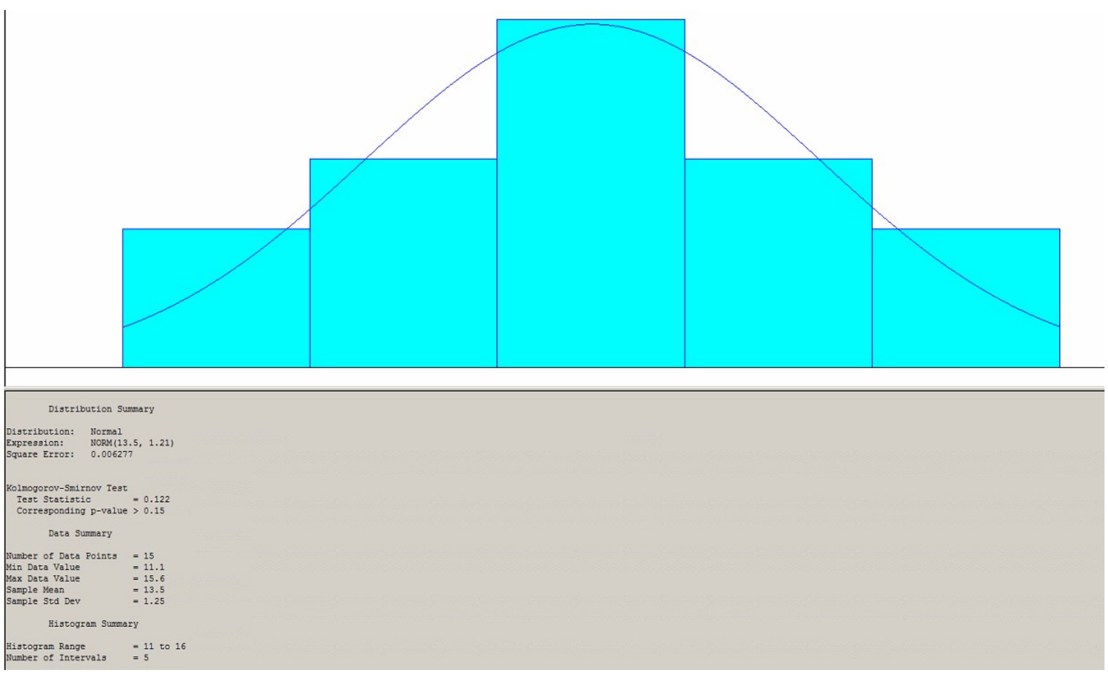
Retrieve time level C



Retrieve time level D



Retrieve time level E



Retrieve time level F and G

Annex I

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	1.6399	0.00	1.6061	1.6702	1.1894	2.4466
Product 2	1.6381	0.00	1.6064	1.6692	1.1911	2.4636
Product 3	1.6425	0.00	1.6076	1.6648	1.1873	2.5218
Product 4	1.6418	0.00	1.6069	1.6769	1.1855	2.4259

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	1.9709	0.00	1.9394	1.9999	1.4851	2.7104
Product 2	1.9693	0.00	1.9400	2.0004	1.5086	2.7031
Product 3	1.9732	0.00	1.9391	1.9947	1.4877	2.7195
Product 4	1.9724	0.00	1.9398	2.0041	1.5112	2.7052

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	13.0611	0.08	11.9050	14.0965	0.00	73.0693
Product 2	12.7910	0.10	11.5304	13.9709	0.00	67.6642
Product 3	12.8552	0.08	11.8806	14.4023	0.00	69.3303
Product 4	12.8068	0.08	11.8930	13.9260	0.00	67.7097

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	0.00	0.00	0.00	0.00	0.00	0.00
Product 2	0.00	0.00	0.00	0.00	0.00	0.00
Product 3	0.00	0.00	0.00	0.00	0.00	0.00
Product 4	0.00	0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	2234.44	9.69	2115.91	2366.62	0.00	22945.63
Product 2	3388.01	30.29	2947.95	3720.63	0.00	53437.34
Product 3	2479.91	6.26	2397.58	2560.77	0.00	10168.92
Product 4	3223.68	11.07	3077.53	3369.01	196.74	16697.65

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	2251.12	9.69	2132.21	2383.41	8.6081	22948.58
Product 2	3404.41	30.30	2964.16	3736.07	8.2420	53457.80
Product 3	2496.38	6.25	2414.80	2577.37	12.5254	10186.65
Product 4	3240.10	11.07	3093.48	3385.24	206.28	16722.38

Entity

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Product 1	1044.04	5.61	980.00	1114.00
Product 2	697.02	5.25	642.00	754.00
Product 3	1875.44	8.52	1786.00	1984.00
Product 4	1385.29	7.57	1306.00	1470.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
Product 1	1010.50	5.61	929.00	1082.00
Product 2	653.84	4.94	593.00	702.00
Product 3	1797.95	8.23	1701.00	1903.00
Product 4	1311.00	7.31	1234.00	1422.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	65.4799	0.43	61.0609	71.7238	17.0000	104.00
Product 2	67.8021	0.80	59.9441	75.6837	16.0000	103.00
Product 3	130.11	0.67	122.79	139.15	33.0000	190.00
Product 4	124.44	0.79	114.30	134.21	25.0000	187.00

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	0.4978	0.00	0.4795	0.5218	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	0.4978	0.00	0.4795	0.5218	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

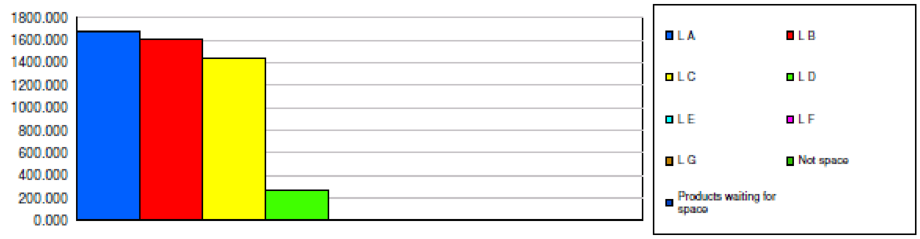
Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Turret	0.4978	0.00	0.4795	0.5218

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Turret	9775.34	24.83	9489.00	10160.00

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
L A	1683.75	7.60	1586.00	1790.00
L B	1600.32	5.50	1531.00	1669.00
L C	1445.45	7.18	1366.00	1534.00
L D	272.27	13.04	136.00	438.00
L E	0.00	0.00	0.00	0.00
L F	0.00	0.00	0.00	0.00
L G	0.00	0.00	0.00	0.00
Not space	0.00	0.00	0.00	0.00
Products waiting for space	0.00	0.00	0.00	0.00



Time Persistent

Variable	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Level A	122.08	0.01	121.93	122.23	91.0000	124.00
Level B	120.04	0.09	118.76	121.01	18.0000	124.00
Level C	105.73	0.46	98.9026	110.17	0.00	124.00
Level D	19.6666	0.96	9.8282	32.6681	0.00	88.0000
Level E	0.00	0.00	0.00	0.00	0.00	0.00
Level F	0.00	0.00	0.00	0.00	0.00	0.00
Level G	0.00	0.00	0.00	0.00	0.00	0.00
Waiting	0.00	0.00	0.00	0.00	0.00	0.00

Annex J

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	1.8463	0.00	1.8092	1.8966	1.1919	3.0811
Product 2	1.8390	0.00	1.8019	1.8818	1.1899	3.0743
Product 3	1.8437	0.00	1.8102	1.8713	1.1899	3.1550
Product 4	1.8385	0.00	1.8023	1.8757	1.1916	3.1024

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	2.1711	0.00	2.1390	2.2177	1.5062	3.2542
Product 2	2.1645	0.00	2.1259	2.2023	1.4999	3.2637
Product 3	2.1686	0.00	2.1370	2.1966	1.5014	3.3226
Product 4	2.1636	0.00	2.1267	2.1969	1.4854	3.2775

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	27.4231	0.29	24.5809	30.4492	0.00	153.15
Product 2	26.8988	0.27	24.2389	29.6015	0.00	140.45
Product 3	26.9628	0.28	24.1043	30.2854	0.00	136.98
Product 4	26.8378	0.29	23.7048	30.0296	0.00	150.54

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	0.00	0.00	0.00	0.00	0.00	0.00
Product 2	0.00	0.00	0.00	0.00	0.00	0.00
Product 3	0.00	0.00	0.00	0.00	0.00	0.00
Product 4	0.00	0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	2492.27	7.05	2393.86	2604.50	0.00	19714.27
Product 2	3573.50	27.40	3233.66	3988.83	0.00	48100.02
Product 3	2491.69	6.00	2414.78	2557.63	0.00	10146.57
Product 4	3258.81	8.96	3125.41	3346.80	144.91	18998.76

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	2523.71	7.08	2423.54	2633.44	10.6276	19730.09
Product 2	3604.40	27.41	3263.93	4017.68	12.0958	48129.12
Product 3	2522.66	6.03	2445.10	2587.09	26.3915	10165.80
Product 4	3289.65	9.02	3154.45	3380.23	181.38	19020.39

Entity

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Product 1	1430.69	8.00	1351.00	1533.00
Product 2	957.89	5.52	889.00	1023.00
Product 3	2581.32	10.10	2452.00	2709.00
Product 4	1904.82	7.63	1822.00	1999.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
Product 1	1393.85	7.56	1324.00	1495.00
Product 2	930.62	5.96	856.00	1000.00
Product 3	2530.71	9.86	2424.00	2664.00
Product 4	1860.62	7.52	1770.00	1944.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	99.69	0.67	91.9469	108.23	44.0000	148.00
Product 2	96.6317	0.91	83.1229	110.03	51.0000	143.00
Product 3	180.29	0.80	171.57	190.54	87.0000	250.00
Product 4	173.33	0.84	160.43	182.89	95.0000	242.00

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Full pallet pick level A.Queue	11.6918	0.16	10.0272	13.2324	0.00	102.47
Full pallet pick level B.Queue	11.6301	0.17	9.4947	13.3094	0.00	98.1781
Full pallet pick level C.Queue	11.6341	0.17	9.7661	13.8367	0.00	93.8287
Full pallet pick level D.Queue	11.7747	0.18	9.7976	13.5753	0.00	94.2933
Full pallet pick level E.Queue	12.1377	0.22	10.0123	14.7678	0.00	107.44
Full pallet pick level F.Queue	1.6170	1.11	0.00	32.6876	0.00	75.4190
Putaway Level A.Queue	9.4021	0.10	8.0478	10.4741	0.00	87.3511
Putaway Level B.Queue	12.4662	0.09	11.6542	13.4994	0.00	90.2479
Putaway Level C.Queue	15.2721	0.09	14.1976	16.3447	0.00	87.6558
Putaway Level D.Queue	20.7399	0.12	19.5496	22.2020	0.00	89.3581
Putaway Level E.Queue	28.8088	0.32	24.8063	32.2689	1.2877	107.02
Putaway Level F.Queue	4.1939	2.59	0.00	62.0116	0.00	84.6118

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Full pallet pick level A.Queue	0.5149	0.01	0.4315	0.5894	0.00	10.0000
Full pallet pick level B.Queue	0.5137	0.01	0.4300	0.5787	0.00	10.0000
Full pallet pick level C.Queue	0.5082	0.01	0.4265	0.6173	0.00	10.0000
Full pallet pick level D.Queue	0.4666	0.01	0.3739	0.5610	0.00	10.0000
Full pallet pick level E.Queue	0.1919	0.01	0.1104	0.3036	0.00	7.0000
Full pallet pick level F.Queue	0.00034829	0.00	0.00	0.00955654	0.00	3.0000
Full pallet pick level G.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Putaway Level A.Queue	0.4143	0.01	0.3459	0.4758	0.00	15.0000
Putaway Level B.Queue	0.5510	0.00	0.5058	0.6096	0.00	17.0000
Putaway Level C.Queue	0.6707	0.01	0.6085	0.7283	0.00	20.0000
Putaway Level D.Queue	0.8751	0.01	0.8016	0.9480	0.00	26.0000
Putaway Level E.Queue	0.4983	0.02	0.2986	0.7335	0.00	25.0000
Putaway Level F.Queue	0.00101405	0.00	0.00	0.02130002	0.00	18.0000
Putaway Level G.Queue	0.00	0.00	0.00	0.00	0.00	0.00

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	0.7609	0.00	0.7363	0.7945	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	0.7609	0.00	0.7363	0.7945	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

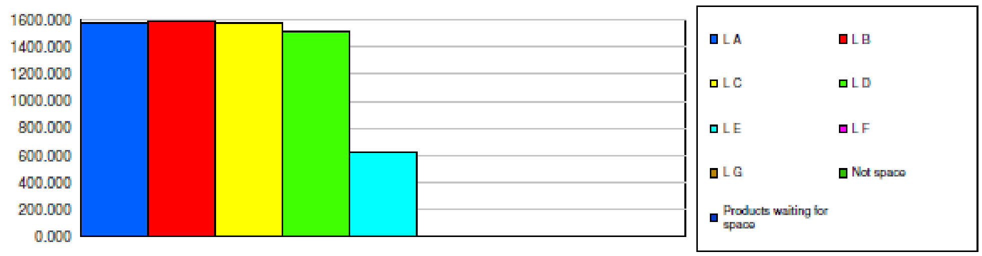
Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Turret	0.7609	0.00	0.7363	0.7945

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Turret	13590.64	35.37	13232.00	14050.00

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
L A	1580.44	7.79	1481.00	1702.00
L B	1585.99	6.42	1507.00	1707.00
L C	1575.51	6.02	1463.00	1641.00
L D	1513.82	7.30	1416.00	1588.00
L E	618.13	19.74	419.00	855.00
L F	0.8300	0.66	0.00	19.0000
L G	0.00	0.00	0.00	0.00
Not space	0.00	0.00	0.00	0.00
Products waiting for space	0.00	0.00	0.00	0.00



Time Persistent

Variable	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Level A	122.40	0.01	122.28	122.54	105.00	124.00
Level B	122.23	0.01	122.00	122.37	101.00	124.00
Level C	121.25	0.04	120.75	121.62	79.0000	124.00
Level D	111.96	0.39	105.62	116.19	0.00	124.00
Level E	44.4466	1.50	27.1237	64.8472	0.00	124.00
Level F	0.05858131	0.05	0.00	1.3939	0.00	19.0000
Level G	0.00	0.00	0.00	0.00	0.00	0.00
Waiting	0.00	0.00	0.00	0.00	0.00	0.00

Annex K

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	2.1153	0.01	2.0404	2.1821	0.00	3.5889
Product 2	2.1006	0.01	2.0265	2.1842	0.00	3.5723
Product 3	2.1153	0.00	2.0521	2.1900	0.00	3.6018
Product 4	2.1050	0.00	2.0530	2.1692	0.00	3.5815

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	2.4018	0.01	2.3187	2.4739	0.00	3.6702
Product 2	2.3885	0.01	2.3132	2.4718	0.00	3.6606
Product 3	2.4017	0.01	2.3331	2.4806	0.00	3.6764
Product 4	2.3922	0.01	2.3334	2.4610	0.00	3.6551

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	514.02	9.62	380.19	613.85	0.00	1096.58
Product 2	507.45	9.44	377.51	622.64	0.00	1066.12
Product 3	514.09	9.41	395.51	625.38	0.00	1133.19
Product 4	506.57	9.31	381.32	607.06	0.00	1098.02

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	0.00	0.00	0.00	0.00	0.00	0.00
Product 2	0.00	0.00	0.00	0.00	0.00	0.00
Product 3	0.00	0.00	0.00	0.00	0.00	0.00
Product 4	0.00	0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	3160.07	12.63	2963.20	3340.73	0.00	24531.97
Product 2	4663.09	20.43	4324.12	4881.80	0.00	57531.87
Product 3	3219.89	9.48	3108.47	3327.41	0.00	18725.48
Product 4	3639.76	12.58	3492.80	3789.07	0.00	24449.06

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	3678.61	15.47	3454.12	3860.28	0.00	25019.75
Product 2	5175.03	22.80	4859.26	5439.21	0.00	57950.63
Product 3	3738.50	14.01	3541.77	3897.39	0.00	19261.23
Product 4	4150.82	14.86	3957.27	4320.47	0.00	24798.41

Entity

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Product 1	1659.96	9.32	1543.00	1824.00
Product 2	1103.32	6.67	1036.00	1209.00
Product 3	2982.69	10.00	2864.00	3138.00
Product 4	2196.37	9.01	2107.00	2305.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
Product 1	1582.73	8.84	1459.00	1756.00
Product 2	1048.77	6.62	972.00	1135.00
Product 3	2842.40	10.15	2715.00	2979.00
Product 4	2102.56	8.71	2011.00	2212.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	174.93	1.15	160.97	192.29	73.0000	247.00
Product 2	156.55	1.15	142.86	173.41	74.0000	212.00
Product 3	316.16	1.57	295.90	337.15	131.00	425.00
Product 4	259.34	1.37	242.60	273.16	140.00	344.00

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Full pallet pick level A.Queue	274.71	5.46	201.49	334.28	0.00	577.30
Full pallet pick level B.Queue	273.65	5.48	199.85	331.64	0.00	572.84
Full pallet pick level C.Queue	274.54	5.43	203.20	336.52	0.00	579.69
Full pallet pick level D.Queue	275.05	5.42	205.22	333.58	0.00	579.92
Full pallet pick level E.Queue	283.43	5.48	209.18	341.62	0.00	573.58
Full pallet pick level F.Queue	311.71	5.77	229.40	375.28	0.00	570.60
Full pallet pick level G.Queue	349.38	3.95	301.87	396.41	0.00	578.94
Putaway Level A.Queue	271.27	5.55	195.43	331.79	0.00	572.32
Putaway Level B.Queue	271.10	5.52	196.22	329.52	0.00	577.04
Putaway Level C.Queue	272.60	5.49	199.34	336.23	0.00	577.42
Putaway Level D.Queue	273.97	5.49	202.36	332.90	0.8316	575.16
Putaway Level E.Queue	270.41	5.37	194.38	333.56	2.5508	577.95
Putaway Level F.Queue	285.00	5.04	217.91	343.62	4.5103	574.96
Putaway Level G.Queue	327.41	3.70	282.18	367.76	8.1682	577.58

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Full pallet pick level A.Queue	8.5565	0.15	6.5398	10.6021	0.00	30.0000
Full pallet pick level B.Queue	8.5219	0.15	6.2987	9.9870	0.00	29.0000
Full pallet pick level C.Queue	8.5163	0.15	6.6117	10.1755	0.00	29.0000
Full pallet pick level D.Queue	8.5369	0.16	6.4600	9.9664	0.00	29.0000
Full pallet pick level E.Queue	8.4648	0.15	6.4282	10.3424	0.00	29.0000
Full pallet pick level F.Queue	8.3916	0.15	6.4078	10.4358	0.00	27.0000
Full pallet pick level G.Queue	7.9895	0.18	5.4307	9.7545	0.00	28.0000
Putaway Level A.Queue	8.3823	0.16	6.3134	10.4399	0.00	33.0000
Putaway Level B.Queue	8.3793	0.15	6.1257	9.8529	0.00	28.0000
Putaway Level C.Queue	8.4000	0.15	6.4776	10.1308	0.00	31.0000
Putaway Level D.Queue	8.4528	0.16	6.3046	9.8435	0.00	31.0000
Putaway Level E.Queue	8.4974	0.15	6.4606	10.3271	0.00	30.0000
Putaway Level F.Queue	8.5720	0.15	6.7267	10.5459	0.00	37.0000
Putaway Level G.Queue	8.5124	0.18	5.9341	10.2427	0.00	47.0000

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	0.9844	0.00	0.9716	0.9975	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	0.9844	0.00	0.9716	0.9975	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

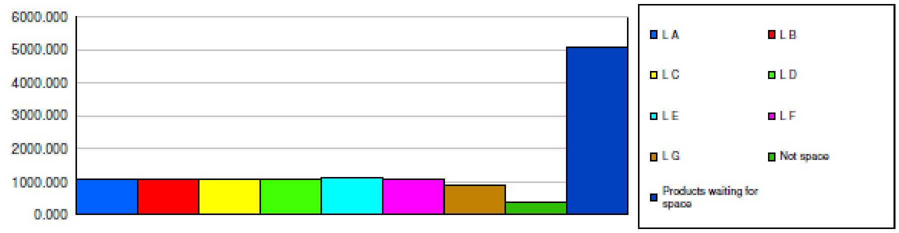
Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Turret	0.9844	0.00	0.9716	0.9975

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Turret	14626.91	11.67	14523.00	14813.00

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
L A	1100.84	5.21	1037.00	1162.00
L B	1100.92	5.17	1038.00	1205.00
L C	1097.61	4.72	1039.00	1164.00
L D	1098.50	4.72	1053.00	1168.00
L E	1119.37	5.37	1051.00	1177.00
L F	1070.96	4.66	1022.00	1129.00
L G	925.07	12.09	748.00	1021.00
Not space	387.56	16.67	189.00	616.00
Products waiting for space	5060.01	137.75	3181.00	6131.00



Time Persistent

Variable	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Level A	123.08	0.02	122.86	123.24	110.00	124.00
Level B	123.05	0.02	122.81	123.21	108.00	124.00
Level C	122.98	0.02	122.78	123.23	102.00	124.00
Level D	122.80	0.03	122.47	123.07	86.0000	124.00
Level E	121.16	0.16	119.14	122.56	8.0000	124.00
Level F	112.23	0.45	106.69	116.52	0.00	124.00
Level G	97.8868	1.35	79.2120	109.28	0.00	124.00
Waiting	51.5463	1.40	32.4556	62.4666	0.00	88.0000

Annex L

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	1.7444	0.00	1.7017	1.7840	1.1904	3.5463
Product 2	1.7733	0.00	1.7143	1.8305	1.1901	3.5493
Product 3	1.7438	0.00	1.7184	1.7811	1.1879	3.5479
Product 4	1.7577	0.00	1.7317	1.7946	1.1915	3.6182

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	2.0694	0.00	2.0285	2.1076	1.5066	3.6465
Product 2	2.0972	0.00	2.0379	2.1506	1.5040	3.6648
Product 3	2.0689	0.00	2.0434	2.1048	1.4922	3.6663
Product 4	2.0819	0.00	2.0567	2.1173	1.5028	3.6533

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	119.60	2.78	78.6981	162.38	0.00	1108.10
Product 2	141.09	3.23	106.24	181.42	0.00	1108.84
Product 3	120.98	2.99	86.5537	165.03	0.00	1139.30
Product 4	126.62	2.79	94.1012	162.68	0.00	1090.58

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	0.00	0.00	0.00	0.00	0.00	0.00
Product 2	0.00	0.00	0.00	0.00	0.00	0.00
Product 3	0.00	0.00	0.00	0.00	0.00	0.00
Product 4	0.00	0.00	0.00	0.00	0.00	0.00

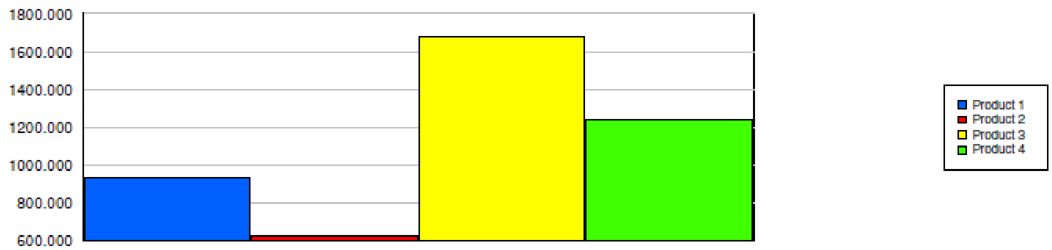
Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	2862.44	11.63	2736.49	3020.38	0.00	23606.72
Product 2	3716.51	26.10	3417.96	4026.21	0.00	58791.46
Product 3	2768.41	7.53	2676.03	2862.86	0.00	19522.00
Product 4	3592.94	13.83	3397.78	3767.35	199.44	29229.85

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	2985.85	11.98	2850.32	3135.02	5.5678	23935.99
Product 2	3861.47	26.69	3548.92	4178.28	8.5010	58809.12
Product 3	2893.21	7.95	2810.19	2982.19	10.9688	20200.05
Product 4	3723.40	13.71	3524.52	3897.99	205.69	29581.59

Entity

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Product 1	933.99	5.70	853.00	997.00
Product 2	625.06	4.37	578.00	670.00
Product 3	1678.27	7.75	1578.00	1774.00
Product 4	1235.49	7.15	1149.00	1358.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
Product 1	1066.10	6.40	966.00	1141.00
Product 2	726.17	5.09	672.00	785.00
Product 3	1916.69	8.24	1813.00	2006.00
Product 4	1412.96	7.49	1324.00	1542.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Product 1	76.1273	0.57	69.6648	83.0182	27.0000	219.00
Product 2	70.4829	0.70	60.8790	80.1007	34.0000	185.00
Product 3	134.47	0.67	125.67	143.93	54.0000	395.00
Product 4	129.26	0.86	119.00	140.39	51.0000	313.00

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Full pallet pick level A.Queue	18.7368	0.65	11.0827	30.9277	0.00	592.64
Full pallet pick level B.Queue	18.6598	0.67	11.0936	28.2019	0.00	591.95
Full pallet pick level C.Queue	21.5711	0.79	11.6381	33.4449	0.00	591.66
Full pallet pick level D.Queue	108.70	4.93	55.0896	178.44	0.00	590.94
Full pallet pick level E.Queue	163.09	6.06	75.9191	243.18	0.00	587.32
Full pallet pick level F.Queue	168.16	5.75	94.9933	233.15	0.00	594.23
Full pallet pick level G.Queue	171.69	6.01	94.7416	249.47	0.00	591.16
Putaway Level A.Queue	21.0155	0.65	13.0140	31.0952	0.00	585.64
Putaway Level B.Queue	24.0399	0.69	16.2765	34.2867	0.00	591.12
Putaway Level C.Queue	29.3015	0.81	19.7904	42.0309	0.00	589.99
Putaway Level D.Queue	165.02	12.29	74.0054	367.59	2.1170	590.97
Putaway Level E.Queue	381.03	9.27	241.62	490.28	171.05	585.28
Putaway Level F.Queue	390.12	10.11	233.96	538.84	186.53	584.90
Putaway Level G.Queue	394.92	10.31	241.41	538.81	212.88	592.74

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Full pallet pick level A.Queue	0.7558	0.03	0.4625	1.2397	0.00	28.0000
Full pallet pick level B.Queue	0.7481	0.03	0.4779	1.0781	0.00	26.0000
Full pallet pick level C.Queue	0.7335	0.03	0.4012	1.1549	0.00	26.0000
Full pallet pick level D.Queue	0.6217	0.03	0.3213	0.9657	0.00	26.0000
Full pallet pick level E.Queue	0.6128	0.03	0.2770	0.9693	0.00	26.0000
Full pallet pick level F.Queue	0.6002	0.02	0.3382	0.8751	0.00	25.0000
Full pallet pick level G.Queue	0.5951	0.02	0.3277	0.9071	0.00	25.0000
Putaway Level A.Queue	0.8491	0.03	0.5453	1.2914	0.00	29.0000
Putaway Level B.Queue	0.9667	0.03	0.6662	1.3503	0.00	27.0000
Putaway Level C.Queue	0.9834	0.03	0.6648	1.2959	0.00	27.0000
Putaway Level D.Queue	0.4585	0.02	0.2040	0.7119	0.00	26.0000
Putaway Level E.Queue	0.3216	0.02	0.1316	0.5171	0.00	25.0000
Putaway Level F.Queue	0.2638	0.02	0.06470145	0.4804	0.00	27.0000
Putaway Level G.Queue	0.2328	0.02	0.07420788	0.5449	0.00	24.0000

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	0.5081	0.00	0.4896	0.5313	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	0.5081	0.00	0.4896	0.5313	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Turret	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

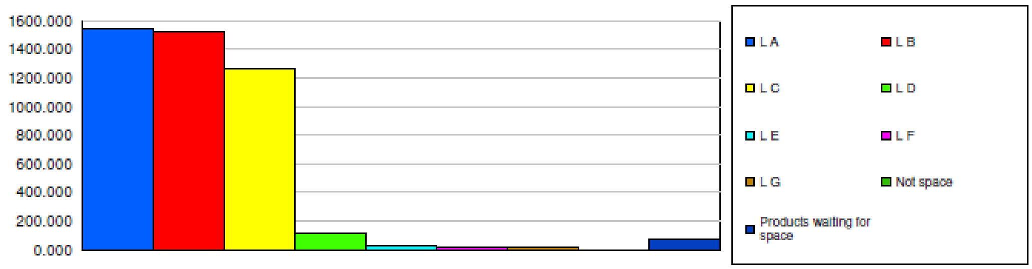
Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Turret	0.5081	0.00	0.4896	0.5313

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Turret	9711.18	27.13	9459.00	10104.00

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
L A	1544.21	5.91	1472.00	1618.00
L B	1526.52	6.53	1447.00	1602.00
L C	1269.94	10.65	1138.00	1409.00
L D	113.69	9.09	27.0000	245.00
L E	25.4000	1.58	9.0000	44.0000
L F	18.8900	1.40	4.0000	37.0000
L G	15.6700	1.26	4.0000	36.0000
Not space	0.00	0.00	0.00	0.00
Products waiting for space	68.0400	4.76	28.0000	133.00



Time Persistent

Variable	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Level A	121.77	0.02	121.58	122.01	77.0000	124.00
Level B	120.82	0.05	119.76	121.35	75.0000	124.00
Level C	102.28	0.78	90.7033	111.53	36.0000	124.00
Level D	17.1342	0.67	10.5266	26.4679	0.00	124.00
Level E	10.5158	0.17	8.5434	12.7835	0.00	124.00
Level F	9.9164	0.17	7.3699	12.3821	0.00	124.00
Level G	9.4897	0.16	7.8596	11.9100	0.00	124.00
Waiting	0.4660	0.04	0.1254	1.0092	0.00	68.0000