Dept of Mechanical, Aerospace and Civil Engineering

Engineering Management, Brunel University

MN5543_CN - Systems Modelling and Simulation Group Assignment

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DIVISION OF WORK AND RESPONSIBILITIES

All the work, from the collection of data in the field to the Distribution Centre system simulation and implementation, has been evaluated and detailed on an agreed plan in the initial meetings.The division was such that every member has contributed with an equal amount of work as the others:

Member	Data Collection	Data Analysis (Input Analyser)	Flow Chart	Report
Margherita Barlotti	▪ Percentage – Parcel and letters by Royal Mail ▪ Delay time – Splitting Mail Out ▪ Delay time – Loading Barrows ▪ Delay time – Serving Customers ▪ Transporters – Porting and Van Delivery	▪ First and second delivery RM for DC ▪ First sorting – Delay time ▪ Parcels storage – Delay time ▪ RM Letters and parcels (2nd delivery - numbers) ▪ Stamping Mail Out	▪ Parcels' Area ▪ Mail and Sorting Area ▪ Station Mail and Parcels for Staff	▪ Introduction ▪ Data Collection ▪ Customers' Area ▪ Parcels' Area ▪ Validation and Verification ▪ Results ▪ Improvements ▪ Conclusion
Federica Bosco	▪ Entities per Arrival – Parcels ▪ Delay time – Unloading bags ▪ Delay time – First sorting Mail ▪ Time between Arrival – Customers ▪ Transporters – Porting and Van Delivery	▪ First and second delivery Letters and parcels ▪ Loading barrows and Van Delivery ▪ Percentage Staff(parcel area) ▪ RM parcels -number of parcels 1st and 2nd delivery ▪ Stamping Mail Out	▪ Parcels' Area ▪ Busy Resources Logic for Routes ▪ Station Mail and Parcels for Staff	▪ Introduction ▪ Data Collection ▪ Mail and Sorting Area ▪ Parcels' Area (RM for DC) ▪ Validation and Verification ▪ Results ▪ Improvements ▪ Conclusion
Pasquale Bucciaglia	▪ Entities per Arrival – Parcel for DC ▪ Delay time – National and International Mail ▪ Delay time – Second sorting Mail ▪ Time between Arrival – Storage ▪ Transporters – Porting and Van Delivery	▪ Percentage of Student Staff Mail - First sorting ▪ Parcels – Arrival time ▪ Processing parcels for DC by RM ▪ 2nd sorting – delay time ▪ Unloading bags -Delay time	▪ Customers' Area ▪ Station Mail Out Area ▪ Station Mail and Parcels for Staff	▪ Introduction ▪ Data Collection ▪ Busy Resources Logic for Routes ▪ Run Setup Parameters ▪ Validation and Verification ▪ Results ▪ Improvements ▪ Conclusion
Fabrizio Valentini	▪ Entities per Arrival – Mail and Parcels by RM ▪ Delay time – Loading Van Delivery ▪ Delay time – Parcel scan ▪ Delay time – Processing Parcels for DC by RM ▪ Transporters – Porting and Van Delivery	▪ Customers – Arrival and Delay time ▪ Parcels scanning – Delay time ▪ RM Letters and parcels (1st delivery-Arrival time) ▪ Splitting Mail Out ▪ Unloading bags -Delay time	▪ Parcels' Area ▪ Station Mail Out ▪ Station Mail and Parcels for Staff	▪ Introduction ▪ Data Collection ▪ Mail and Parcels for staff Area ▪ Mail Out Area ▪ Validation and Verification ▪ Results ▪ Improvements ▪ Conclusion

INTRODUCTION

The Group Project consists in utilising the capabilities of Systems Modelling and Simulation in order to design and analyse a real system: the Distribution Centre in Brunel University.

The introductory briefing obtained from the Manger allowed visiting the business and roughly understanding the main operations executed by the Distribution Centre around the entire University. This was necessary in order to clearly plan and equally share the work between the group members that would have been done in the following month.

With an official permission and having respected the Health & Safety policies in force in the Distribution Centre premises, the data collection has been carried out (with the great support of the staff) following a unanimously agreed schedule in which the plan for the whole collection was detailed laid out.

The intuitive problem solving and the engineering approach have been applied to the investigated system so that the relevant data concerning the arrival and distribution of mail were appropriate and statistically true to reality.

In fact, the use of statistics and probability theories allowed simulating the Distribution Centre in Rockwell Arena, giving a detailed report of the performance of every process that subsequently has been used to perceive where the system can be improved with validated what-if scenarios.

2. 1 – The System: The Distribution Centre

The Distribution Centre of Brunel University is located on the South Perimeter Road, alongside the Antonin Artaud building, in the Joseph Lowe building.The processes involved in the centre are based on the delivery system adopted by Royal Mail as reported by the manager.

It offers a wide range of services that provide support to the complete Campus and they can be divided in:

- **Mail:**
  The external and internal mail is processed and distributed once in the morning and once in the afternoon. This fixed schedule can be subjected to variation (one delivery instead of two) in case of special events or activities held on Campus.

- **Porterage:**
  The principle services are:
  - Office furniture moves.
  - Bulk print collection/deliveries.
  - Refuse collection from designated areas on campus.
  - Daily replenishment of toilet supplies.

  The porterage exclusively work through an Operation Booking System when the order (with a minimum of 48 hours' notice) concerns furniture moves, decants and bulk prints. On the contrary, waste collection and toilet replenishment take place on a daily basis with departments' individual requests dealt as soon as possible.

- **Central Stores / Good Inwards:**
  The offered services include:
  - Receipt and Distribution of parcels and packets.
  - Limited storage of stationary and janitorial stock items.

With an organized scheme that involves all the employees, the busiest services are found in the **Mail and Central Stores / Good Inwards sections**.

The warehouse can be mainly divided in two major operative parts in which the core activities of the previously mentioned duties take place:

- **Mail area**
  The mail area is the one subjected to the receipt of Royal Mail Delivery. With one delivery scheduled not after 8.30am and one in the afternoon at 1.30, the staff collect A4, A5 standard letters, A4 flat parcels and various packets. This mail can comprehend both student and staff items.
  The area is organized as such so that flow of letters and parcels is continuous and efficient, and it comprehends:
  - Rear Entrance: Royal Mail delivers through this door with apposite bags. This is connected with the sorting area.
  - Parcel Sorting Area: In here, the student and staff parcels of certain dimensions are electronically received and subsequently moved into the Parcel Area
  - Mail Sorting Area 1: The available mailbags are here sorted by 2 employees by general department with the use of appropriate pigeonholes.

- Mail Sorting Area 2: The mail divided in the previous area is here sorted even further taking into account the specific building to where it is addressed.
- Mail-Out Area: the letters that need to be sent nationally or internationally by the University Departments is here stamped with Royal Mail certified machines and disposed in specific boxes waiting for collection.

- **Parcels Area**

  On the contrary, the Parcel Area deals with all the ordered packages (for students and staff) delivered by numerous couriers and the customers (students) requiring a package throughout the working day. The regular presence of staff permits the prompt receipt of the parcels with an electronic signature and the sorting in the specific shelves. This area is divided as follow:

  - Main Entrance: This large access point allows the loading and unloading of large quantities of parcels (or furniture when necessary) using trolleys and carts.
  - Customer Entrance: This corridor with a desk permits the customer to queue if necessary, request and collect a previous registered postal item.
  - Registration Desk: In here, the delivered packages are registered into the system with the help of barcode scanners.
  - Shelves: The registered parcels are placed in the shelves according to the building of destination.
  - Porterage Stock: This is an area reserved to all those goods that address the essential needs of various departments, activities and events across Brunel University (registration, graduation, lectures, labs, exams etc.).

2. 2 – Operating Times

The three main services provided are carried out during the opening times Monday to Friday. The working day start at 8.00am for all the staff. The manager and the Team Leaders discuss the plan for the day from 8.00am to 8.20am with a briefing, as well as dividing the work between the other employees.By the first arrival of Royal Mail estimated for around 8.30, everything needs to be properly set up and the staff ready.The Distribution Centre closes at 4.00pm.

2. 3 – Human Resources

The entire staff of Brunel Distribution Centre accounts for 10 people including one Manager and two Team Leaders.

Their working times coincide with the opening times of the premises and therefore they follow an 8.00am – 16.00pm, Monday to Friday shifts.The same staff is entitled of one-hour lunch break at 2pm that usually coincide with the quietest period of the day, where the students are in lectures and not many couriers are expected. However there is an exception: at least one person has to be present in the customers' area even if break time in order to guarantee the continuity of the service.

2. 4 – Machines

The purpose of any distribution centre is to control the movement and storage of goods in the most efficient possible manner. However, the main machine used during the processes involved in this system is represented by a bar code scanner. A reliable and accurate database can be maintained through this tool, by simply scanning parcels when they are going through the storage process.

The collected data can be uploaded to a central computer system in real time, allowing a better inventory management and providing efficiency and accuracy that would otherwise have to be imposed manually.

Furthermore, it has been observed that using an effective scanning solution can contribute to keep velocity in service by optimizing and automating activities that improve employee productivity and reduce errors in the picking process.

Brunel Distribution centre is provided with:

- **Parcel area**: 2 bar code scanners and 2 computers
- **Mail area**: 1 bar code scanner connected to 1 computer and 2 stamping machines

2.4.1 - Failures

The failures that will be applied to the machines present in the distribution centre will be based on the observations done and the data obtained through the staff.

The failures will be defined as follow:

- **Failure Human Resources:**
  The Distribution Centre's General Manager confided us that, according to the previous historical data, an average of 1 employee per month requests a day off due to illness or private reasons. As a matter of fact, during the collection of data, just one failure of human resources was witnessed.
- **Failure Machines:**
  The main utilized machines concern the process of the parcels' storage (PCs and Bar Code Scanners) and the stamping of mail-out (Franking/Stamping Machines):these affect the availability of the entire process to which they are subjected. Other machineries which are involved in secondary activities such as office's computers have not been considered because their availability implies that they do not have implications in the simulated system.

Failure - Advanced Process

	Name	Type	Up Time	Up Time Units	Down Time	Down Time Units	Uptime in this State only
1	Failure Human resource	Time	30	Days	1	Days	
2	Failure Machine	Time	30	Days	6	Hours	

Figure 1 - Resources' Failures

2. 5 – Transporters

While incoming goods are received, these after being sorted out, have to be shipped to the correct destination (departments and shops); by contrast, goods addressed to students are stored into the warehouse, and do not require the use of transporters.

The transporters used in the system for delivering staff are three vans and three barrows. More specifically, the latter are handled by three workers (one for each track), are routed to the closest destination, following a specific pathway and require approximately 30 minutes to make a complete round to the fixed destinations; instead, the van is handled by one worker to the furthest areas which cannot be easilyreached and takes approximately 40 minutes.

Furthermore, both vans and barrows, start their round at around 9:30am (after the first sorting), and make another round as soon as the second sorting is completed (at around 1:30pm). However, it is important to highlight that only some departments are involved in both rounds, making the second round faster and shorter.

All transporters are involved in the delivery of mail around campus according to the following routes:

- **Route 1: Van Delivery**

The van delivery route shown in Figure 2 is the more time consuming delivery path. In addition to the longer list of serviced buildings compared to the other routes, the van is constrained to outer circle around campus (highlighted in blue). Once near the delivery points, the employees appointed to this itinerary, need to park the van and finish the delivery on foot.

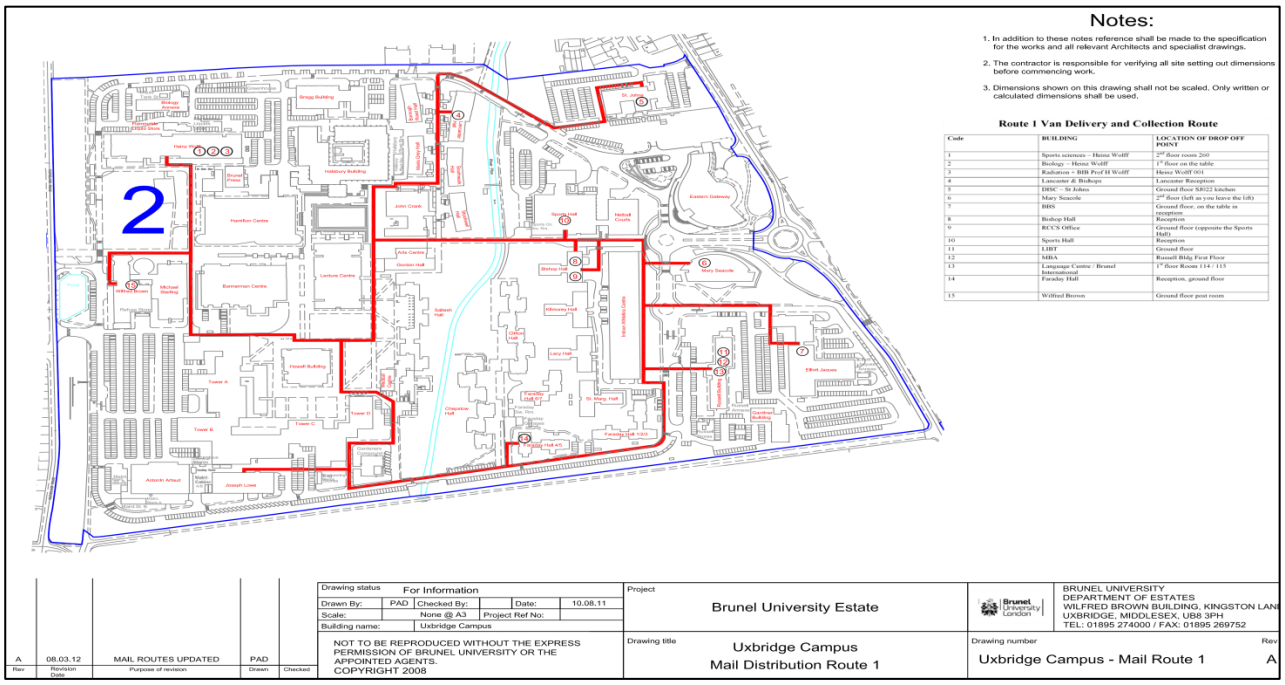


Figure 2 - Route 1, Van Delivery

- **Route 2: Halsbury**

The so called Halsbury route is the delivery schedule that addresses the consignment of mails and parcels across the buildings touched by the main artery of the University spreading from south to north of the campus (Figure 3).

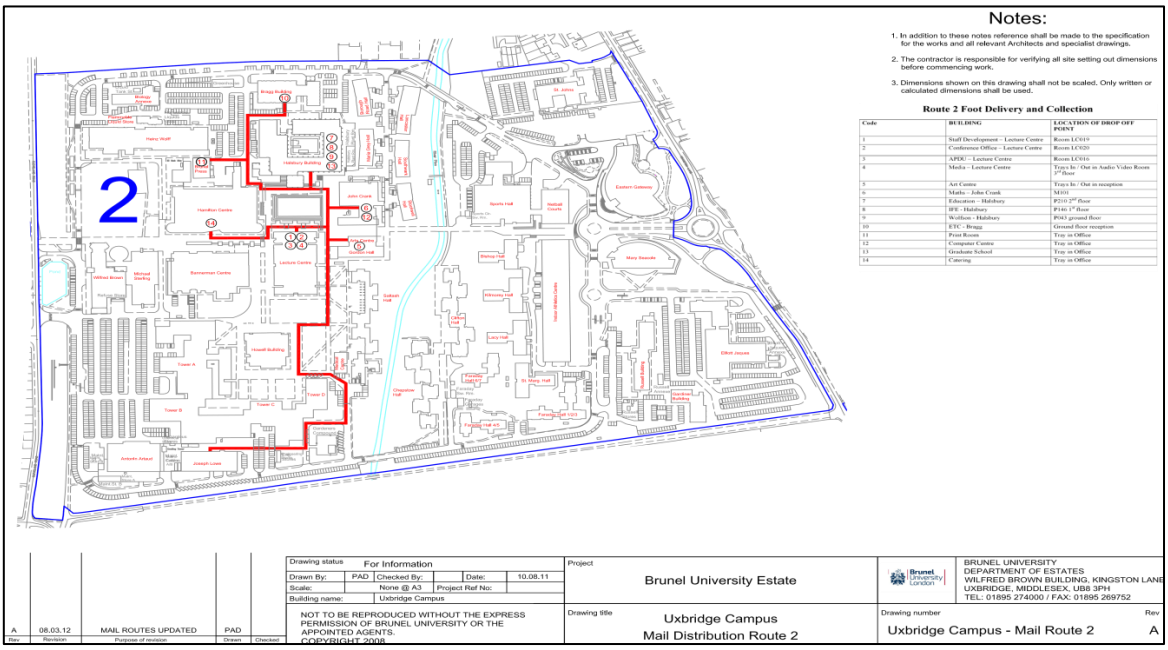


Figure 3 - Route 2, Halsbury

- **Route 4: Engineering and Design**

The Engineering and Design route (Figure 4) concerns the Southern part of campus where all the main buildings linked to these subjects are established.

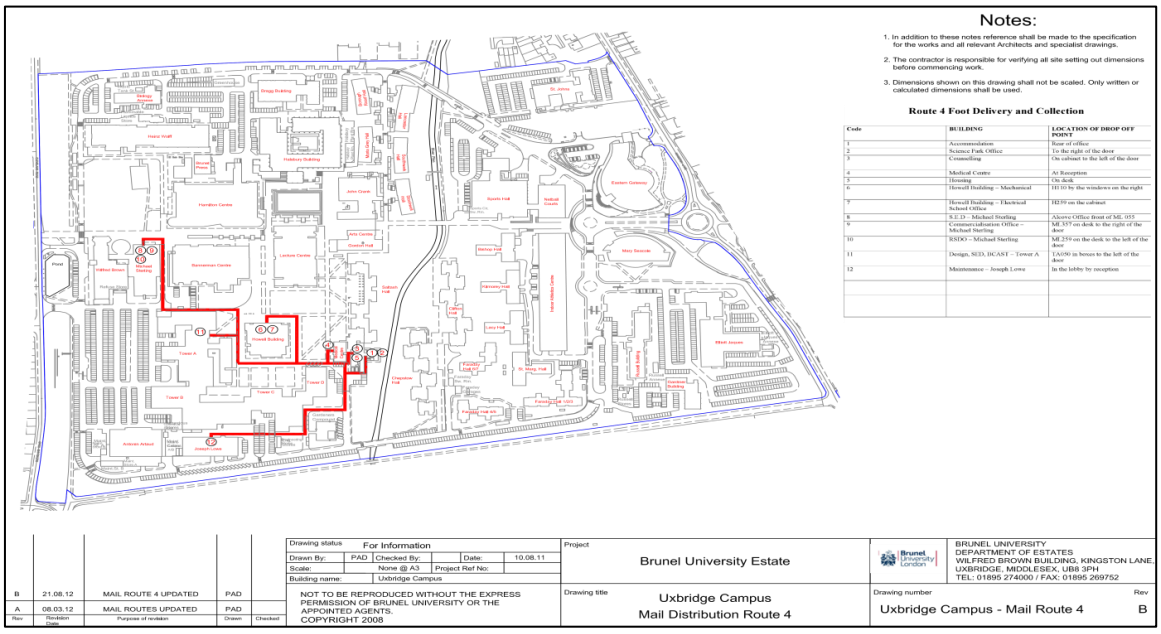


Figure 4 - Route 4, Engineering and Design

- **Route 5: Social Sciences**

Figure 5 represents the delivery of mail and parcels for the buildings of social science and residences that are situated on the west part of campus. Even if this side of the campus is mainly managed by the Isambard Residence Offices, the Distribution Centre still deliver for some of their buildings.

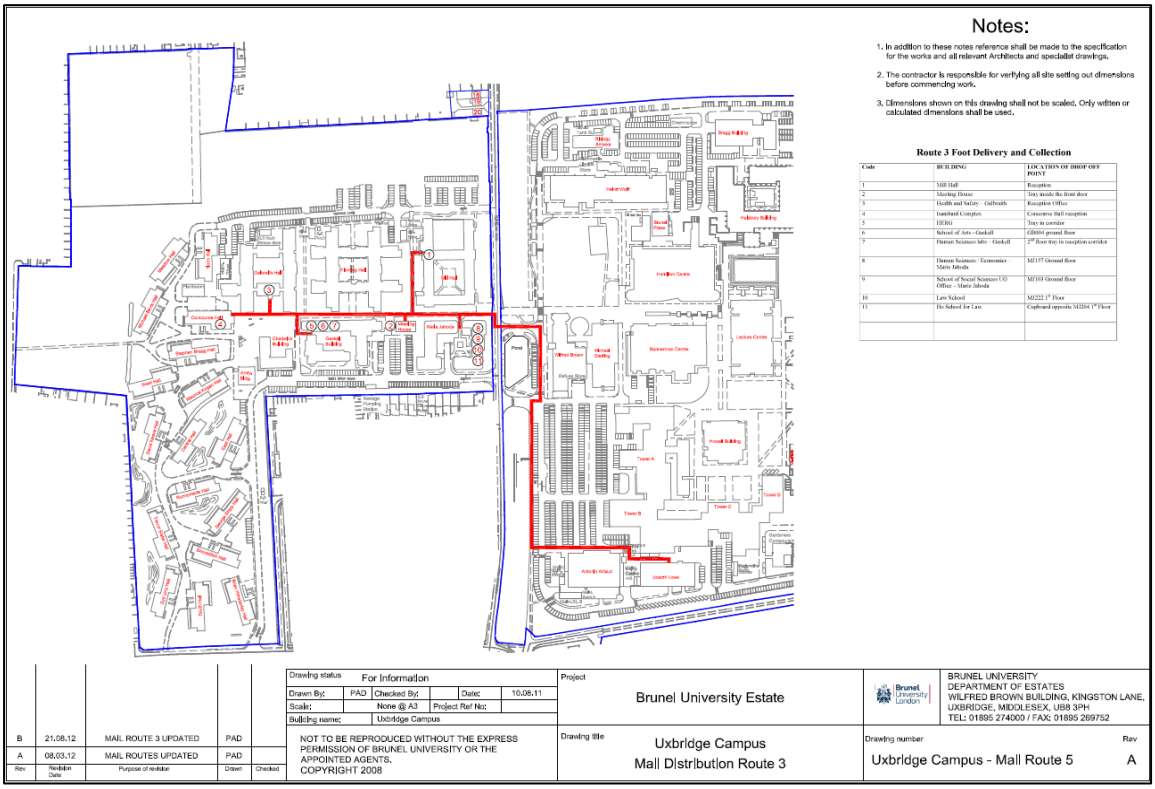


Figure 5 - Route 5, Social Sciences

2. 6 – Assumptions Made

Some assumptions have been made during the modelling of the Distribution Service in order to ease the translation of reality into simulation and they can be listed as follow:

- The porterage offered by Brunel Distribution Centre has not been addressed in the final simulation: in fact, since all the activities present in this service do not happen on a regular basis, not sufficient data were collected to portray it in a statistically valid manner.
- The served customer will receive the first parcel arrived in the Parcel Area.
- Due to the important amount of vans available, the delivery vehicle has been model as a transporter and therefore is not subjected to failures. Barrows do not present failure either.
- The van delivery has been scheduled with one delivery per day (in the morning) instead of two.
- Two designated employee have a different lunch break time from the rest of the colleagues in order to guarantee the continuity of the customer service.

DATA COLLECTION

Due the amount of parcels and mails dealt with during an average working day, each member of the group has followed the pre-scheduled plan for the collection of data presiding the designated section.

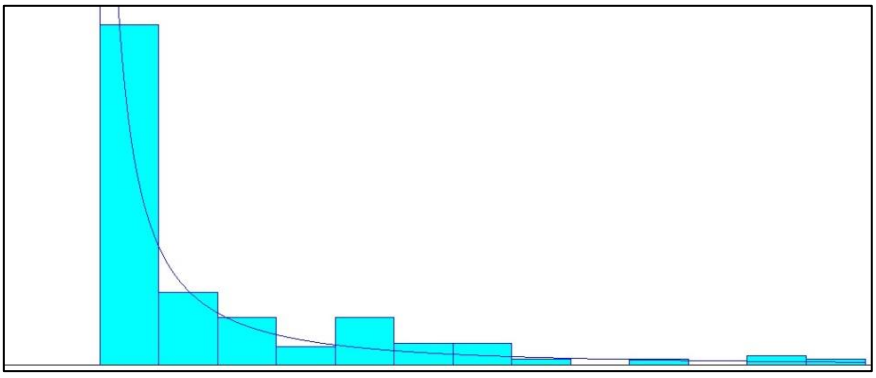
The process-time for each workstation has been calculated by observing and clocking manually (through the use of a chronometer) the activities of the employees using a numerical time value in seconds for each process and in minutes for the deliveries.

These data have consequently been analysed in the Input Analyzer tool available in Arena: here they are statistically validated while fitted with the most suitable random statistical distribution.

The complete list of the collected data relative to the Distribution Centre's processes can be found in the Appendix as a separate booklet. The distributions achieved from Input Analyzer are the following:

3.1 – Customers (Students), Entities per Arrival

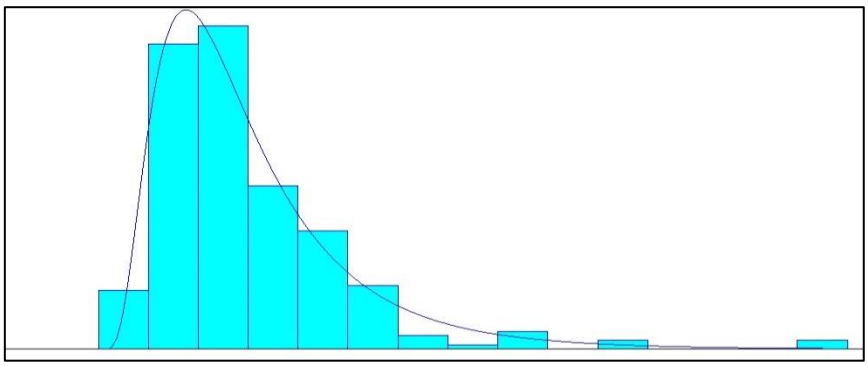
Students randomly come and request parcels at the relative service desk. Analysing the data it can be seen (in the schedule utilised in the flowchart) how these arrivals spike at lunch times and drop coinciding with usual lecture times.



Distribution	Expression	Square Error
Lognormal	$-0.001 + LOGN(22.8, 162)$	0.004466

3.2 – Customers' Service, Delay Time

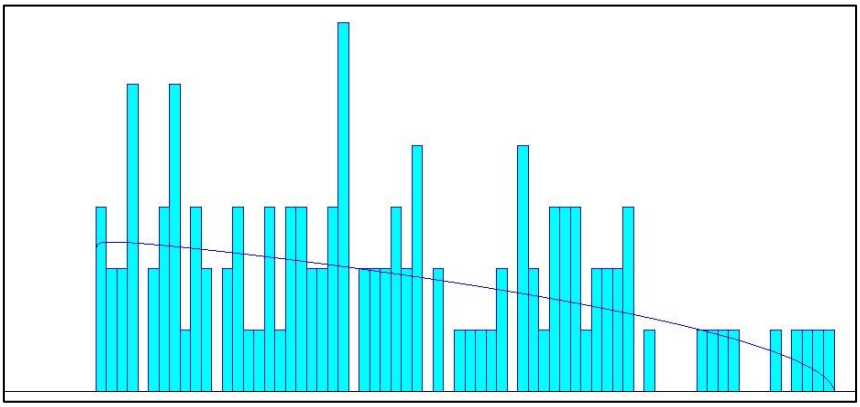
When the student ID is scanned, the DC[1] operator goes to the stock shelves, collects the right package and delivers it to the customer, who is authorized to leave the premises with the object after an electronic sign of receipt.



Distribution	Expression (Minutes)	Square Error
Lognormal	$LOGN(2.03, 1.36)$	0.002527

3.3 – Parcels, Entities per Arrival

Parcels arrive randomly in groups delivered by various couriers. The parcels are unloaded from the van, transported into the premises and received by an operator that signs the electronic tracking device.

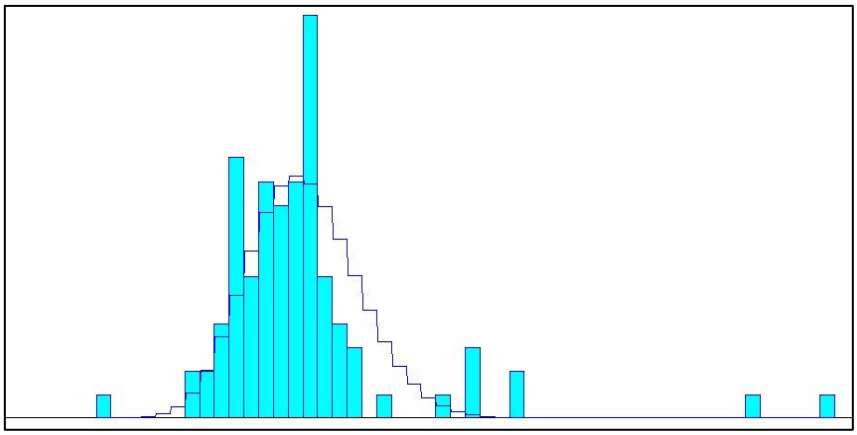


Distribution	Expression	Square Error
Beta	$-0.5 + 70 \cdot BETA(1.01, 1.55)$	0.007407

[1] Distribution Centre

3.4 - Parcels Scanning, Delay Time

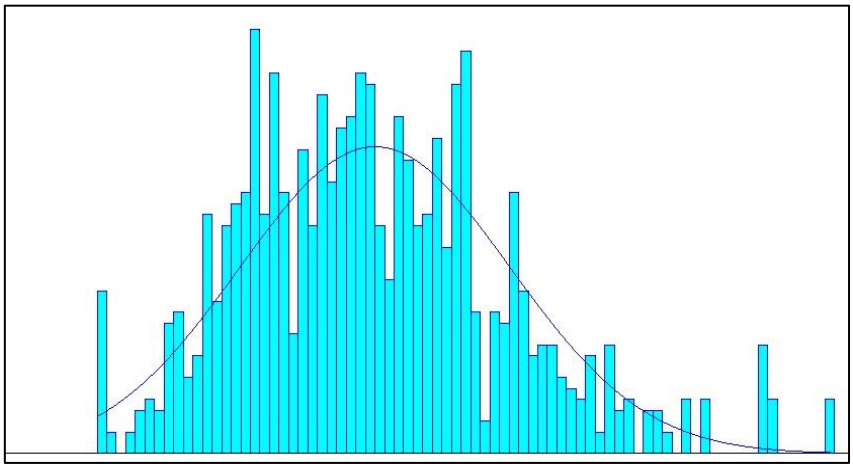
The arrived packages are here registered into the University's system so that the recipient is notified with an e-mail. With the help of the two barcode scanners connected to two computers, the operators can automatically register the parcel into the mail system inserting all the relevant information.



Distribution	Expression (Seconds)	Square Error
Poisson	$POIS(13.6)$	0.019057

3.5 - Parcels Storage, Delay Time

While one or two people register the parcels, another employee collects the already processed ones and store them in the close-by shelves, respecting the division by building.

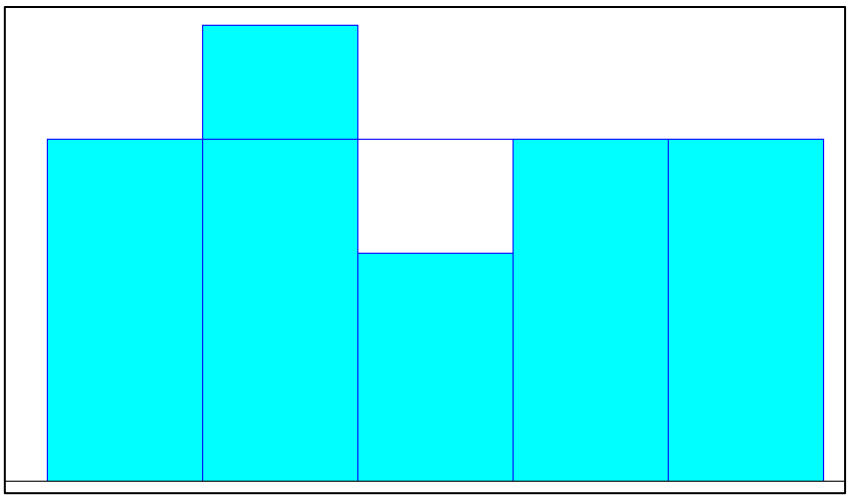


Distribution	Expression (Minutes)	Square Error
Normal	$NORM(28.5, 14.1)$	0.002783

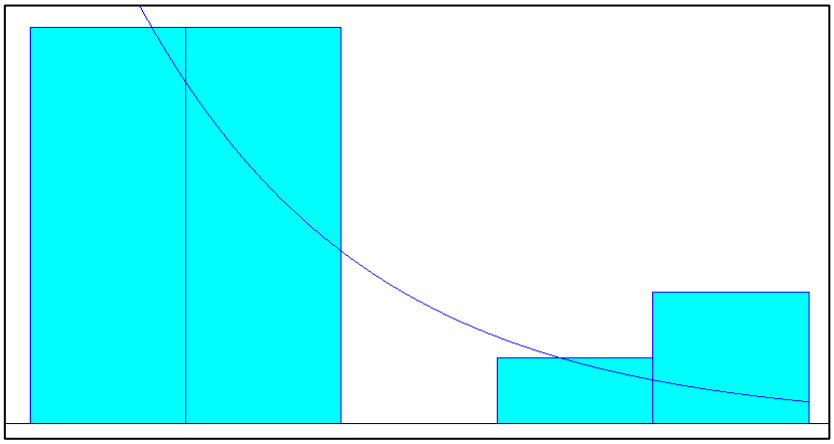
3.6 - Royal Mail (Letters and Flat Parcels), Entities per Arrival

Letters and Flat Parcels arrive daily following two scheduled time, as already specified. The aid of bar code scanners replaces manual documentation, allowing employees to handle boxes by reading a unique label on them; through this system, mail couriers will experience a considerable reduction in process time and therefore errors which is significant for business practices. The relative former distributions for parcels and letters are related to the 1st delivery and the latter represent the 2nd.

- Letters

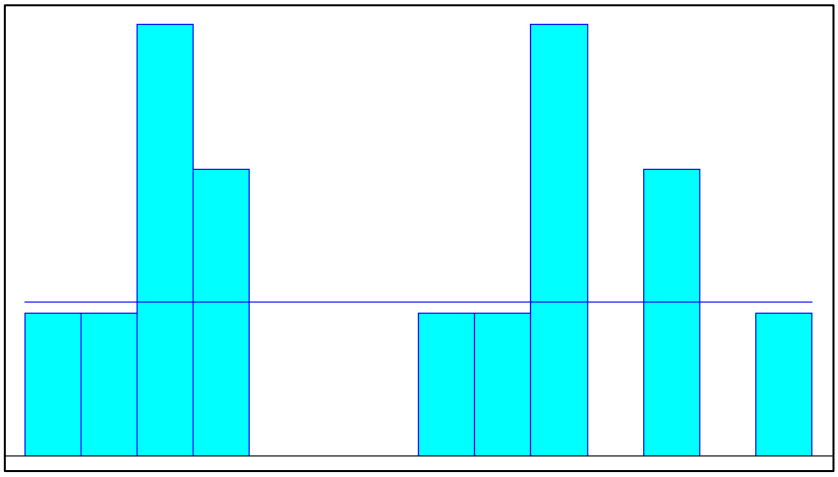


Distribution	Expression (Minutes)	Square Error
Uniform	$UNIF(731, 2.33e+003)$	0.008889

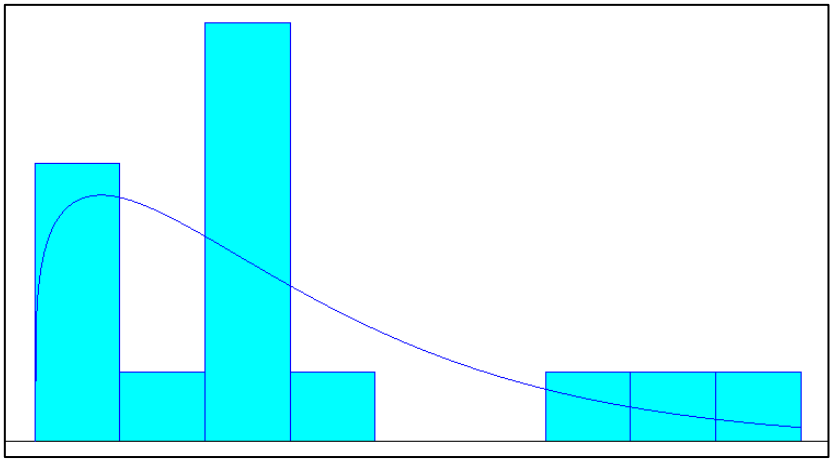


Distribution	Expression (Minutes)	Square Error
Exponential	$236 + EXPO(267)$	0.057725

- Parcels



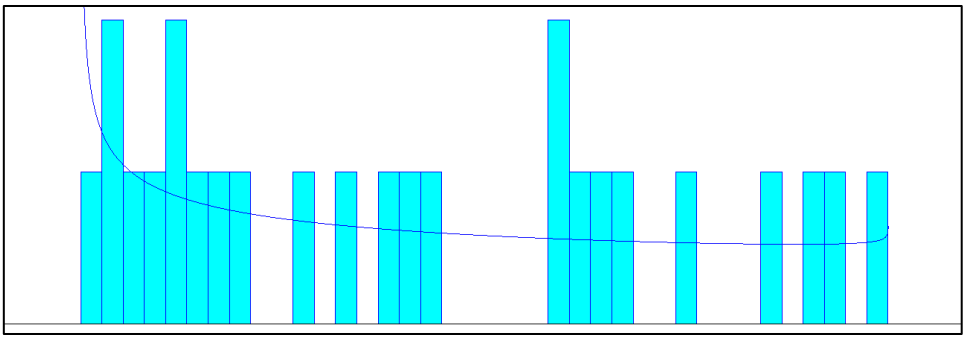
Distribution	Expression (Minutes)	Square Error
Uniform	$UNIF(6.5, 20.5)$	0.066349



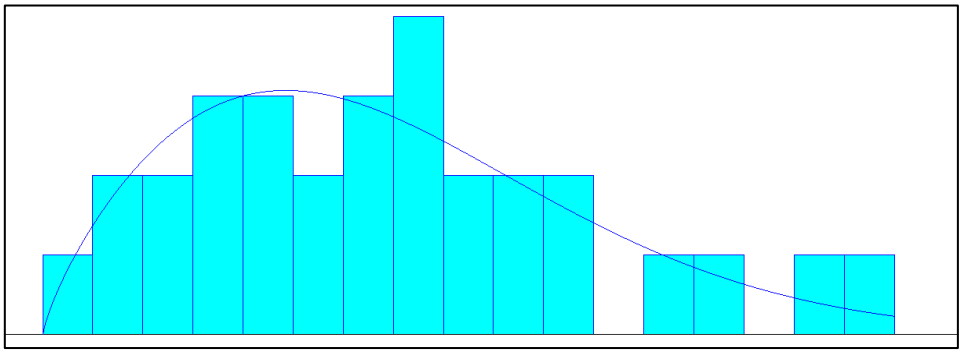
Distribution	Expression (Minutes)	Square Error
Weibull	$1.5 + WEIB(3.17, 1.22)$	0.097081

3.7 - Royal Mail (Parcels for DC Parcels Area), Entities per Arrival

When Royal Mail delivers the mail and the flat parcels, it carries another postal box with inside big parcels that have been ordered by either staff or student. These packages are destined to the Distribution Centre Parcels Area, where they need to be processed and registered inside the system following the same procedure as the ones delivered by the private couriers.



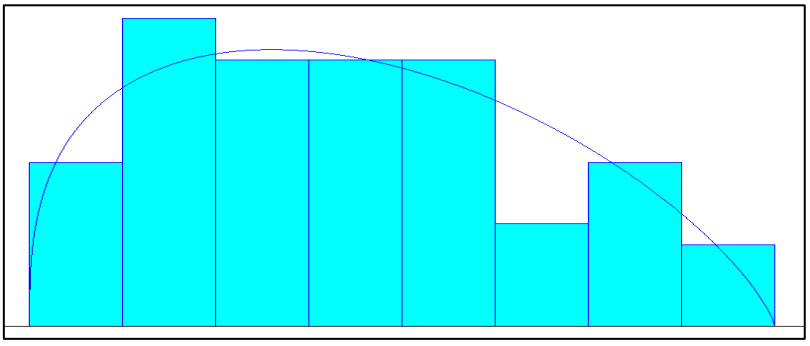
Distribution	Expression (Minutes)	Square Error
Beta	22.5 + 38 * *BETA*(0.731, 0.966)	0.020351



Distribution	Expression (Minutes)	Square Error
Weibull	1.5+WEIB(7.78,1.77)	0.020351

3.8 - Processing Parcels for Distribution Centre by Royal Mail, Delay Time

Before being transferred to the parcels area, at the moment of the delivery by the postman, these parcels are electronically signed for and disposed on a table.

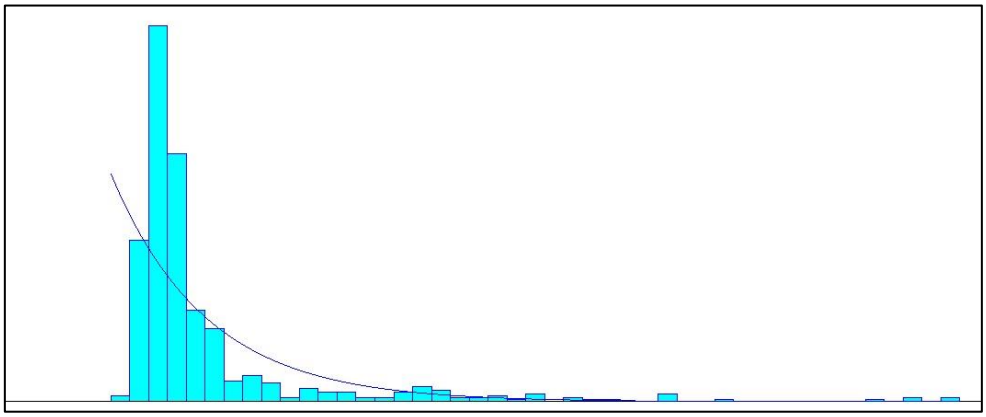


Distribution	Expression (Seconds)	Square Error
Beta	$1.5 + 8 * BETA(1.36, \quad 1.74)$	0.005368

3.9 - Mail First Sorting Process, Delay Time

Figure 6 - Wooden Pigeonholes for the First Sorting

Once mailbags arrive, these are sorted by 4 employees according to a meticulous inspection: more specifically, the first sorting starts at around 8:30 and letters are collected in appropriate pigeonholes. In detail, there are eight different compartments (whose 2 are in common and six doubled) in which letters are collected and sorted before being delivered to the proper destination (Shops, Halsbury, Social Science, Engineering and Design, Van Delivery, Residences).

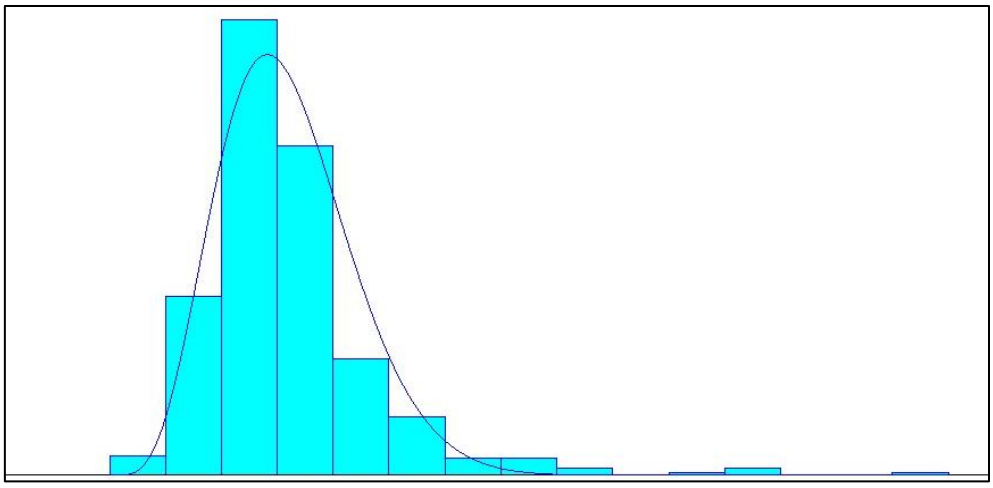


Distribution	Expression (Seconds)	Square Error
Exponential	$0.5 + EXPO(5.04)$	0.090281

3.10 - Mail Second Sorting Process, Delay Time

Figure 7 - Metal Pigeonholes used for the 2nd Sorting

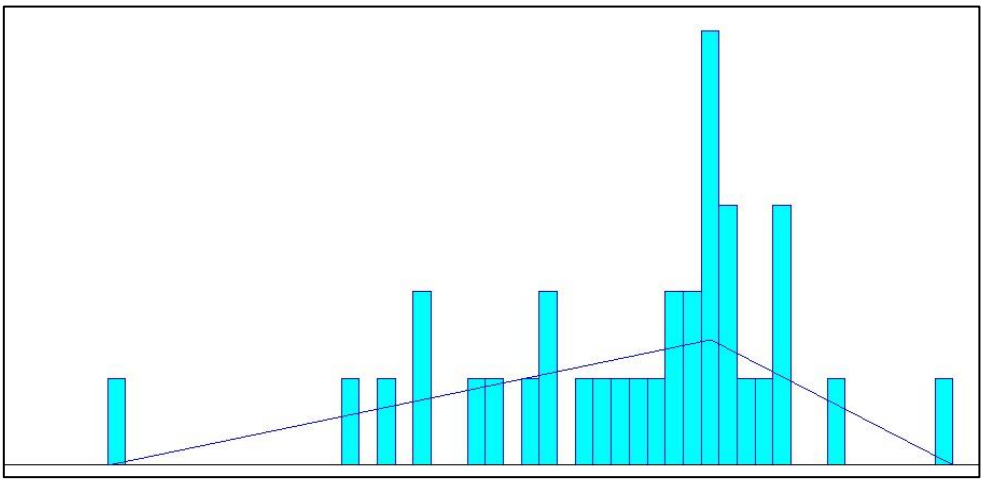
The Second sorting starts at around 1pm and differently from the former, requires less workers considering the less amount of letters which arrive and consequently, less time. However, as it can be predicted, on Monday the amount of letters is three times as much of that receipt the other days, due to the stack created at the week-end where Royal Mail does not deliver.



Distribution	Expression (Seconds)	Square Error
Beta	$0.5 + 15 * BETA(5.52, 20.6)$	0.007603

3.11 - Unloading bags, Delay Time

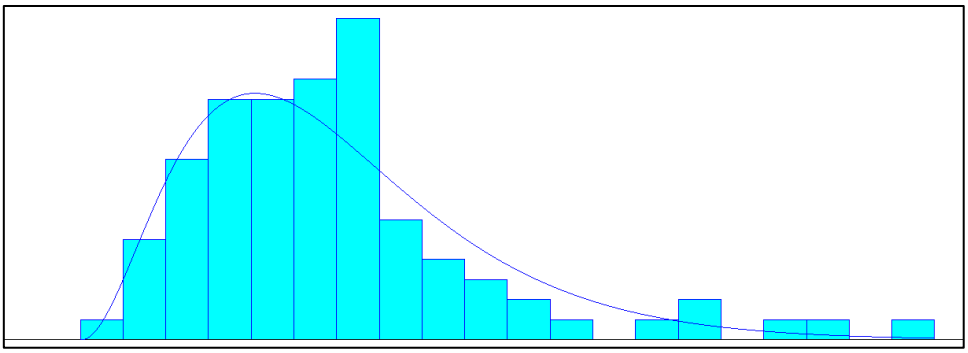
This step involves two employees who have the main task to unload bags (containing letters and parcels) in order to separate and bring them in their specific area. Therefore, according to the Royal Mail delivery time, this process follows two scheduled time and takes few minutes to be completed.



Distribution	Expression (Seconds)	Square Error
Triangular	$TRIA\ (3.5, 37, 50.5)$	0.028813

3.12 - Loading barrows, Delay Time

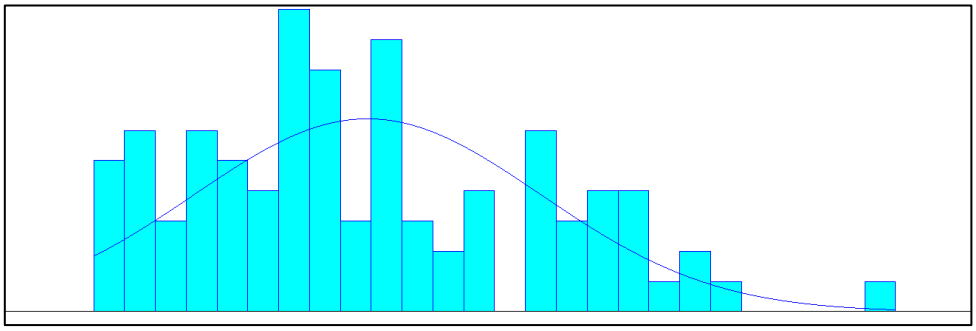
When all the letters and flat parcels from Royal Mail have been sorted twice (once by department and once by building), they are loaded in the barrows for route 2, 4 and 5 and the manual delivery can be commenced.



Distribution	Expression (Minutes)	Square Error
Poisson	$POIS\ (6.48)$	0.009074

3.13 - Loading Van Delivery, Delay Time

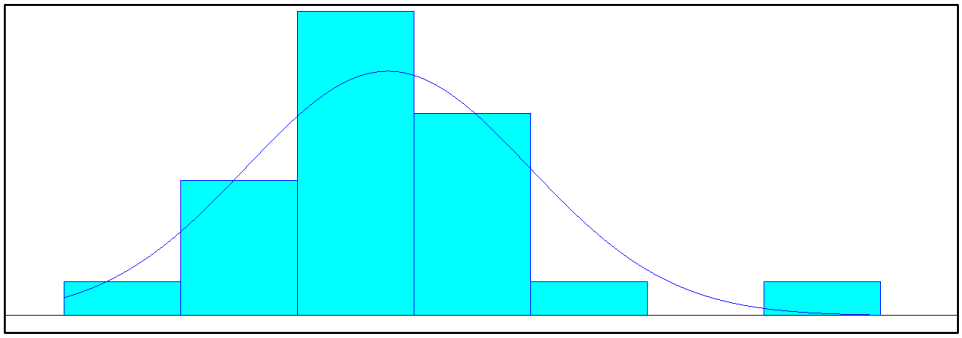
When departments and building that receive a vast quantity of mail are involved, the DC van gets loaded with all the available letters and flat parcels lumped in bigger groups.



Distribution	Expression (Minutes)	Square Error
Normal	$NORM\ (18.4, 5.62)$	0.015160

3.14 - Splitting Mail-Out, Delay Time

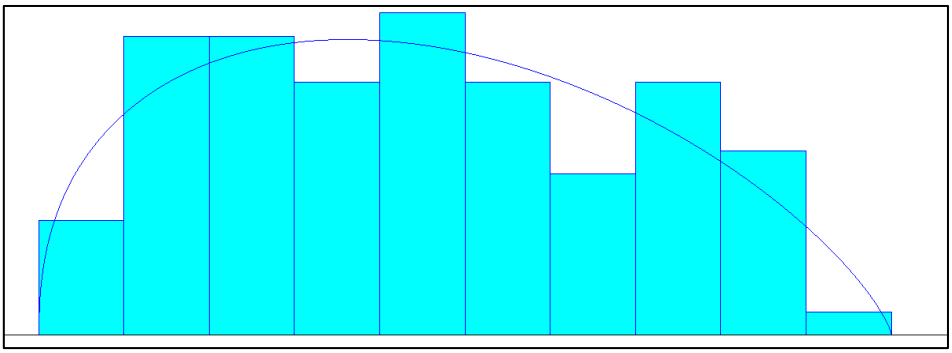
As said before, the Distribution Centre receives a considerable quantity of mails that need to be sent nationally or internationally. Before the stamping, this amount of letters necessitate to be sorted and split according to the before mentioned two categories.



Distribution	Expression (Minutes)	Square Error
Normal	$NORM\ (3.27, 1.21)$	0.018245

3.15 - Stamping Mail-Out, Delay Time

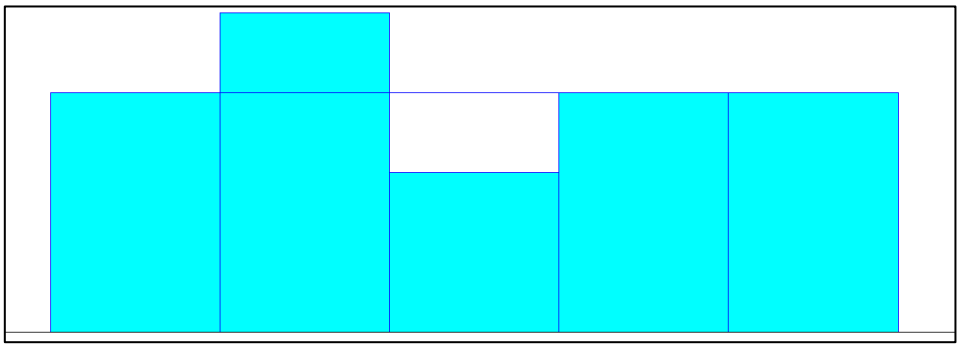
Once the mail has been divided, the employee will stamp each letter (charging the sending department) with the relative two Royal Mail machines.



Distribution	Expression (Minutes)	Square Error
Beta	0.5 + 10 * BETA(1.43, 1.75)	0.004376

3.16 - Percentage Staff (Parcel Area), Decide by Chance

According to its random distribution, the received parcels that are destined for the university staff may vary day by day.



Distribution	Expression (%)	Square Error
Uniform	$UNIF(39, 49)$	0.008889

FLOWCHART ANALYSIS

The simulation model has been created by using Arena Software (Version 14.5) and has been divided into different main areas as following:

- CUSTOMER'S AREA
- PARCEL'S AREA
- MAIL AND SORTING AREA
- PARCEL'S AREA (ROYAL MAIL FOR DISTRIBUTION CENTRE)
- MAIL AND PARCELS FOR STAFF AREA
- BUSY RESOURCES LOGIC FOR ROUTES AREA
- MAIL OUT AREA

4.1 – Customers Area

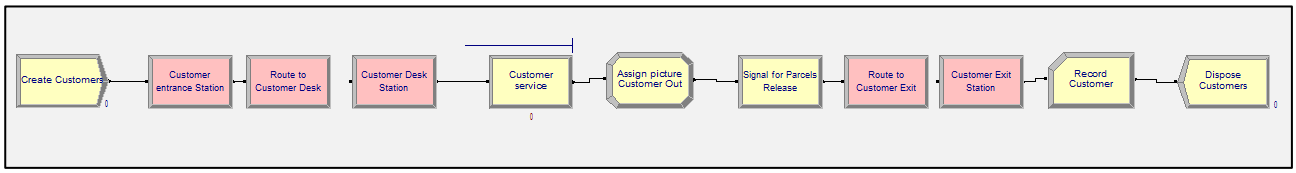


Figure 8 - Customers arrival

The customer's area gathers all students who come to collect their stocked parcel after they have received an email alert. This process has been basically reproduced through the use of *Create, Process, Signal* and *Dispose* modules.

4.1.1 - Create Customers

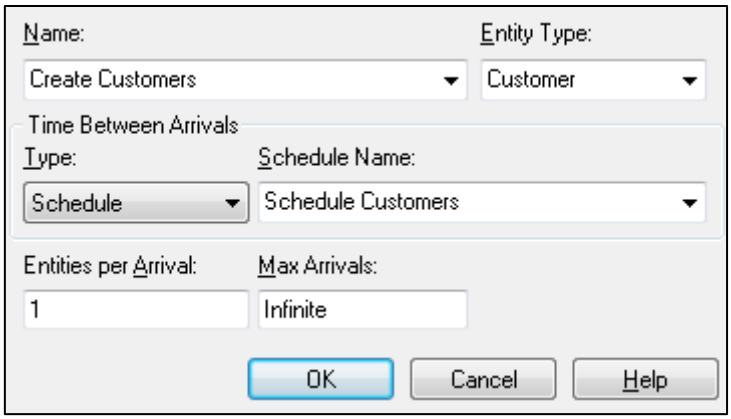


Figure 9 - Create Customers Module

The *Create Customers* module generates customers entering the system, following a specific schedule. The collected data have shown that on average, the number of customers who arrive throughout the day reaches its peak during lunch time (1:00pm-2:00pm), due to the fact that during this hour the majority of students are free from classes; however, data have been utilised

to create a distribution that has been put into the *Schedule Customers* module as shown in *Figure 10.*

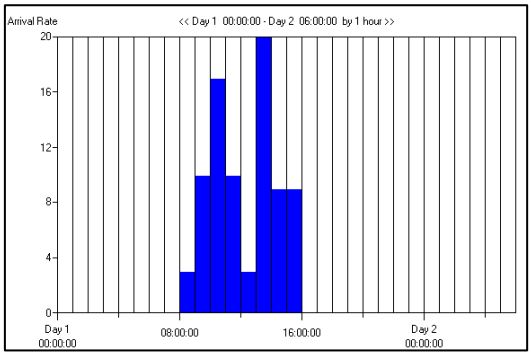


Figure 10 - Create Customers' Schedule

4.1.2 - Customer Service

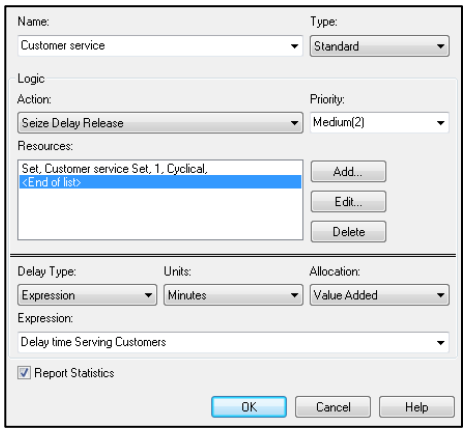


Figure 12 - Customer Service Process

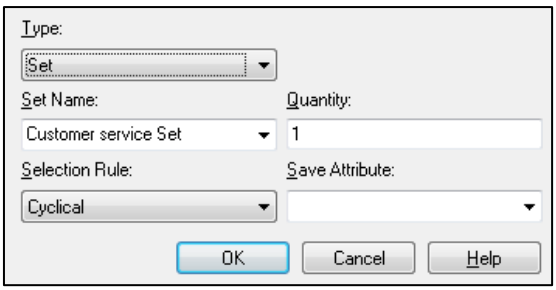


Figure 11 - Customer Service's Resource Set

Customers who enter the system are served by one employee who is not involved in other processes. The distribution utilised to describe this process follows a *LOGN(2.03, 1.36)minutes* and it is included in its relative variable. However, taking into account that the number of customers who arrive daily is on average 35, this process is not considered as main as the others and consequently, does not require particular commitment. More specifically, it has been observed that as soon as the customer arrives, the first idle employee goes to the desk service in order to serve him/her. To better clarify this statement, the "Resources" involved have been put into a Set module, which helps to understand their cyclical role (as shown in Figure 13).

	Resource Name
1	Amanda
2	Jack
3	Michael
4	Andreas
5	Frank
6	Marc
7	Igor
8	Kevin
9	Tim
10	Carl

Figure 13 - Customers Service Set Order

Moreover, the scheduled working time for the employees is the following:

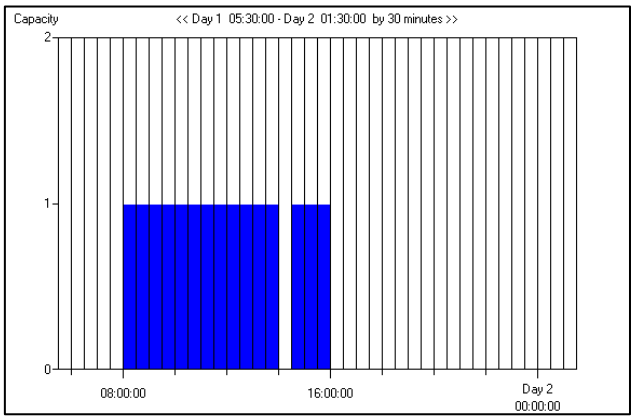


Figure 14 - Schedule Employees

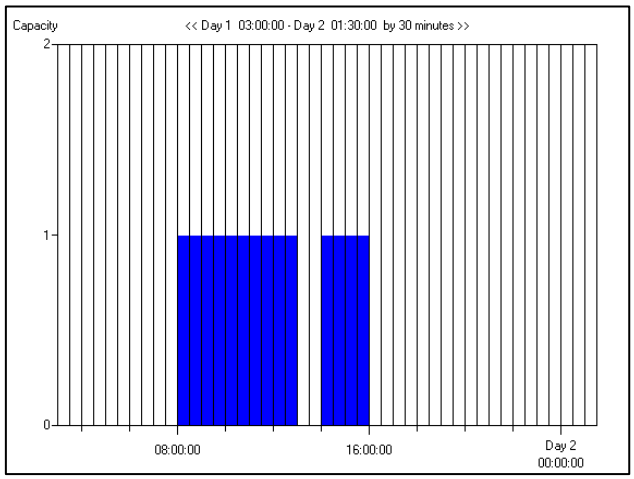


Figure 15 - Schedule Employees 2

As can be seen from *Figure 14* and *Figure 15*, two different schedules for employees have been created. More specifically, as already specified, the customer service involves the first idle employee not busy in other processes. For this reason, in order to guarantee that customers will be served as soon as possible (avoiding long waiting time), it has been assumed that the break taken by two employees is different from that one taken from the rest of the team, allowing in this way an ongoing process service.

4.1.3 - Signal for Parcels Release

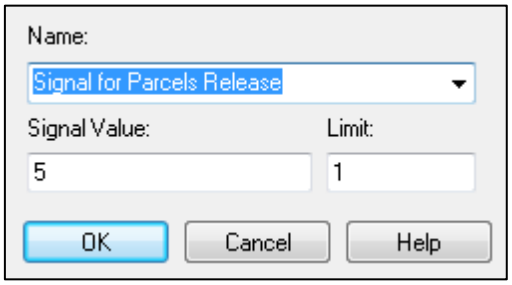


Figure 16 - Signal for Parcels Release Module

Because there is a strict connection between customers and parcels (being the latter allocated to the former), it has been thought to use a Signal module that literally sends a Signal for parcels to

be released when a Customer is being processed. Furthermore, the *Limit* for releasing parcel has been put equal to 1, to specify that one parcel per time is going to be released for each customer.

4.2 - Parcels Area

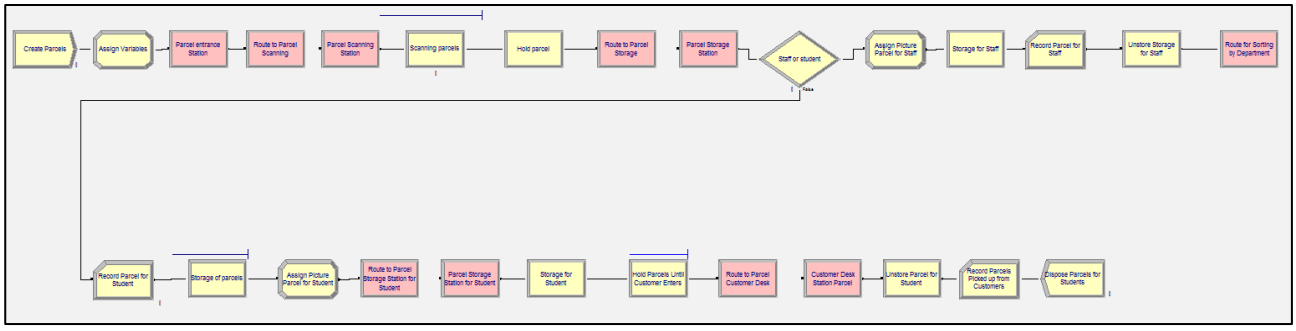


Figure 17 - Parcel's Area

The Parcel's area gathers all parcels which have been ordered (from both students and staff) and which are delivered by numerous couriers. This process represents one of the main processes done inside the Distribution Centre.

4.2.1 - Create Parcels

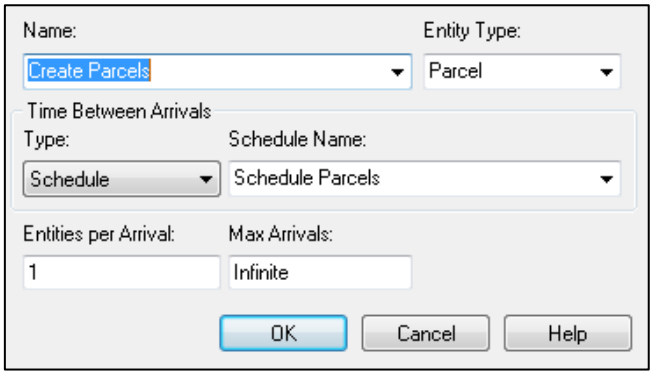


Figure 18 - Create Parcels Module

For this Create module has been used the same logic as done for the Customers Create module. The distribution carried out from the collected data has turned out to be *-0.5 + 70*BETA (1.01, 1.55) seconds.*

	Value	Duration
1	0	8
2	-0.5+70*BETA (1.01, 1.55)	8
3	0	8
	Double-click here to add a new row.	

Figure 19 - Schedule Parcels Creation – Durations

4.2.2 - Assign Variables

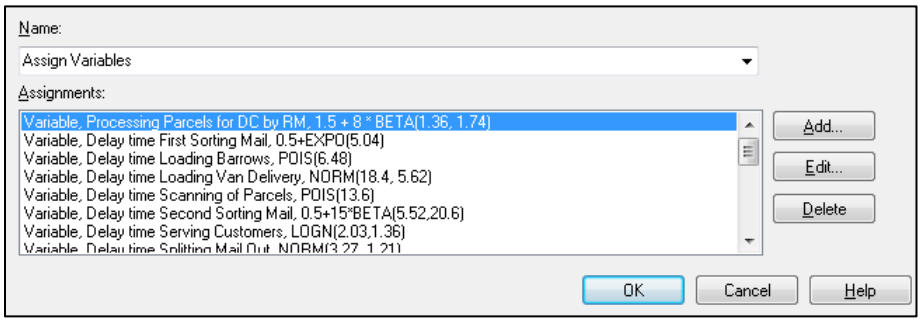


Figure 20 - Assign Variables Module

The Assign module has been introduced to "assign" variables throughout the processes present in the simulation model with the main purpose of easily recalls them when they occur. However, once defined each variable, its relative distribution has been allocated in the *New Value* box.

4.2.3 - Parcels' ScanningStation

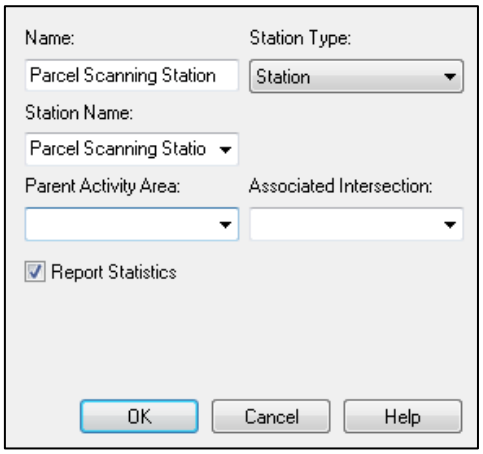


Figure 21 - Parcels Scanning Station

This station represents the "physical" place where parcels are transferred (after being unloaded from couriers), before going through the scanning process.

4.2.4 - Scanning Parcels

This process consists in scanning parcels by using a bar code scanner, in order to manage the storage of goods addressed to staff and students. However, two employees (Amanda and Jack) who use two computers as resources to upload the data coming from processed parcels, have been allocated to that area, making sure that the process is represented properly. In detail, after being seized, it has been noticed that the processing time for each parcel follows POIS *(13.6)* seconds, after that parcels are released in order to be stored in the appropriate shelves.

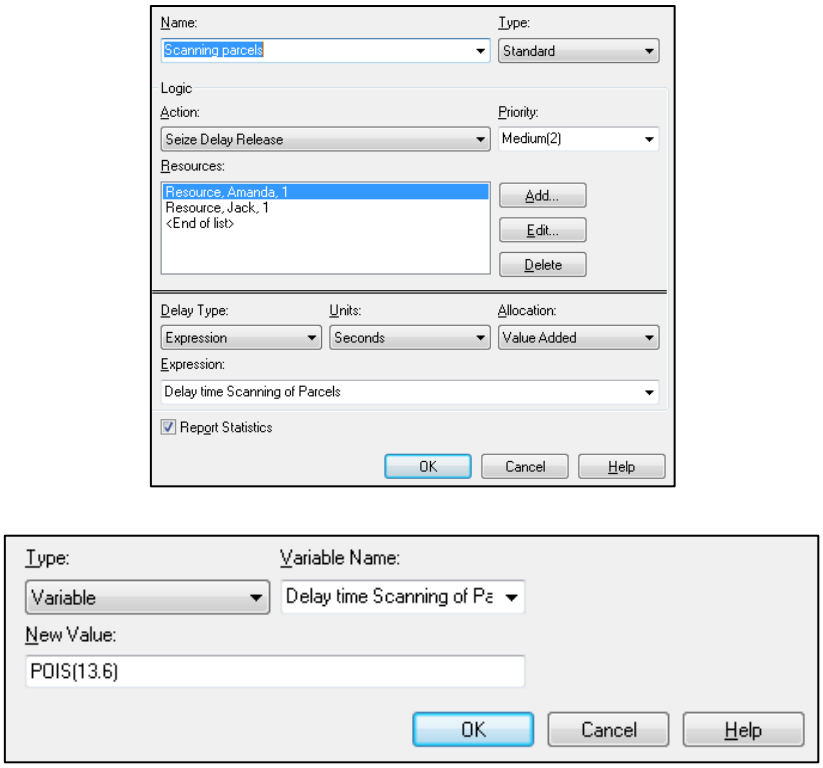


Figure 22 - Scanning Parcels Process

4.2.5 - Hold Parcels

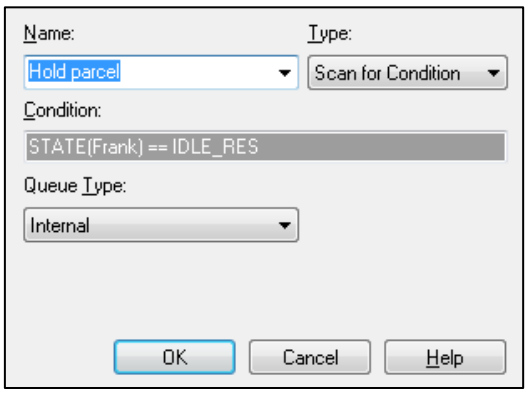


Figure 23 - Hold Parcels Module

As soon as the scanning process is completed, parcels go through a storage process, which takes the presence of one employee. However, the *Hold parcel module* type chosen to represent what happen into the system is *Scan for Condition;* the latter, clarifies that if the current state of the employee (in charge for that process) is idle, then parcels can be processed; otherwise, these have to wait before proceeding to the following step.

[Expression: STATE(Frank)== IDLE_RES]

4.2.6 - Decide Staff or Student

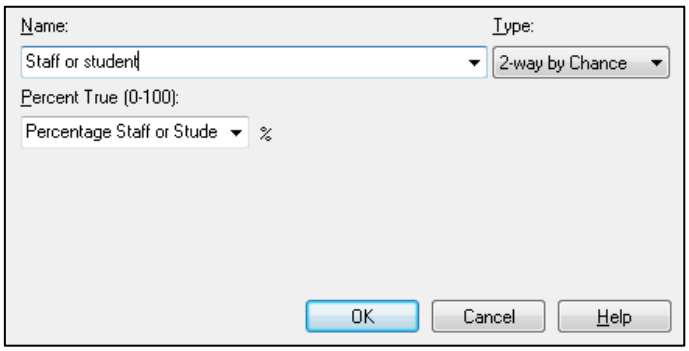


Figure 24 - Staff or Student Decide Module

In order to allow a better inventory management and provide efficiency and accuracy, the Distribution Centre organizes its shelves precisely. For this purpose it has been considered useful to put a decide module. More specifically, the latter has the main aim to split the amount of parcels which need to be stored for coming students from the amount of parcels which are addressed to the University staff. The percent true has been defined with a random distribution variable which ensures that the quantity of student/staff mail changes accordingly with the collected data:

UNIF(39, 49)

However, both of them go through a store module but following a different path, that will be explained at a later stage.

4.2.7 - Storage for Staff

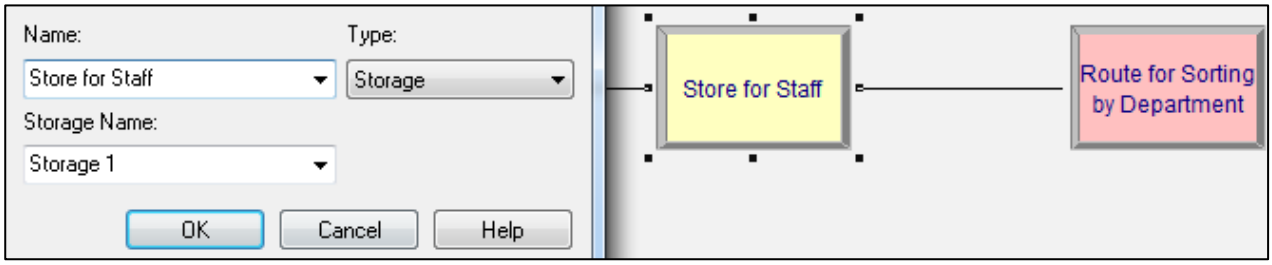


Figure 25 - Store for Staff Module

On the one hand, parcels addressed to the staff are then sent to the other area of the Distribution Centre in order to be sorted out, according to a set of features.

4.2.8 - Storage of Parcels

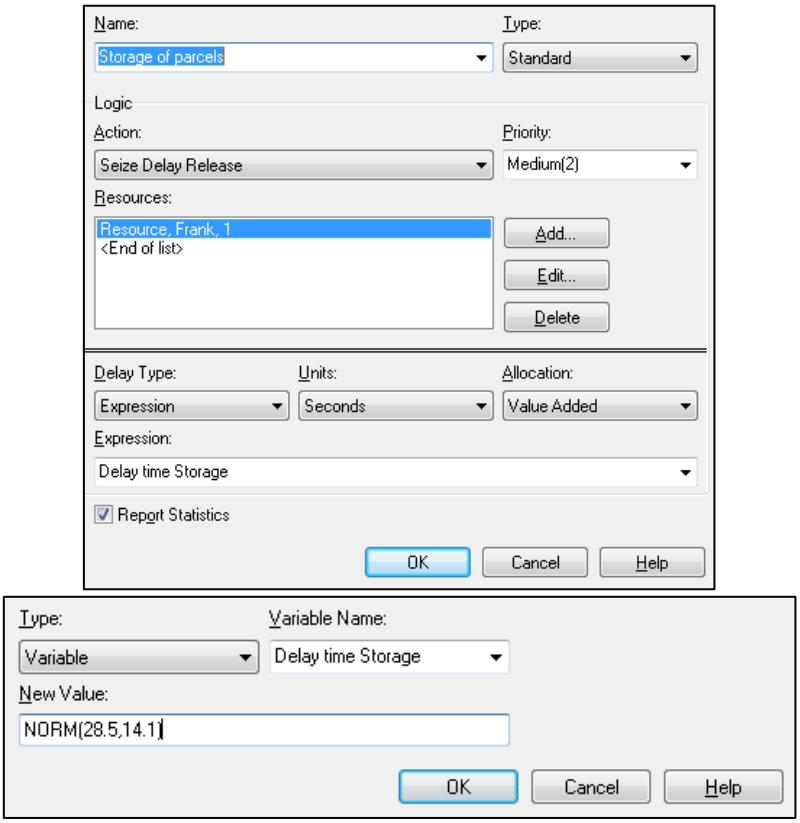


Figure 26 - Storage of Parcels Process

Once that all parcels have been scanned, these need to be stored. This process, has been thought to be managed by one employee (Frank) and has turned out to take *NORM(28.5, 14.1)* seconds. However, the responsible employee of this process is simultaneously involved in other processes; this statement clarifies the role of the hold module that has been established before.

4.2.9 - Store for Student and Hold Parcels until customer enters:

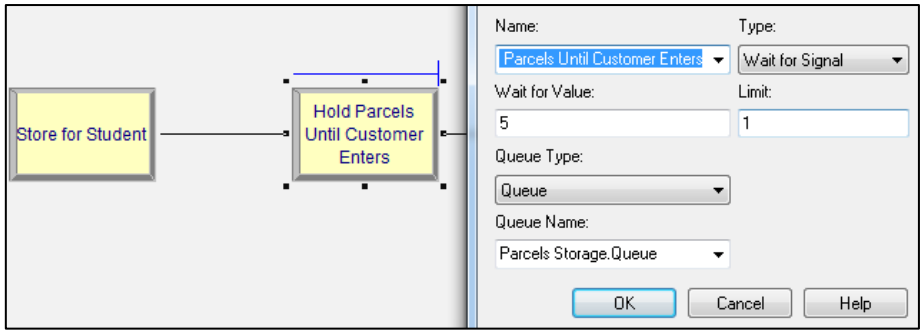


Figure 27 - Store for Student and Hold Parcels Module

On the other hand, parcels addressed to students are stored into the parcel's area where are processed. In this context, the Hold module has the main purpose to hold parcels as soon as customers come to withdraw them. For this reason, it has been thought to choose a *Wait for*

Condition Type, according to which parcels will be hold until a signal of the same value (5 in this case) is received and then released.

However, it is important to remember that this module is linked to the Signal module analysed before, where is possible to specify the signal that makes the condition true.

4.3 - Mail and Sorting Area

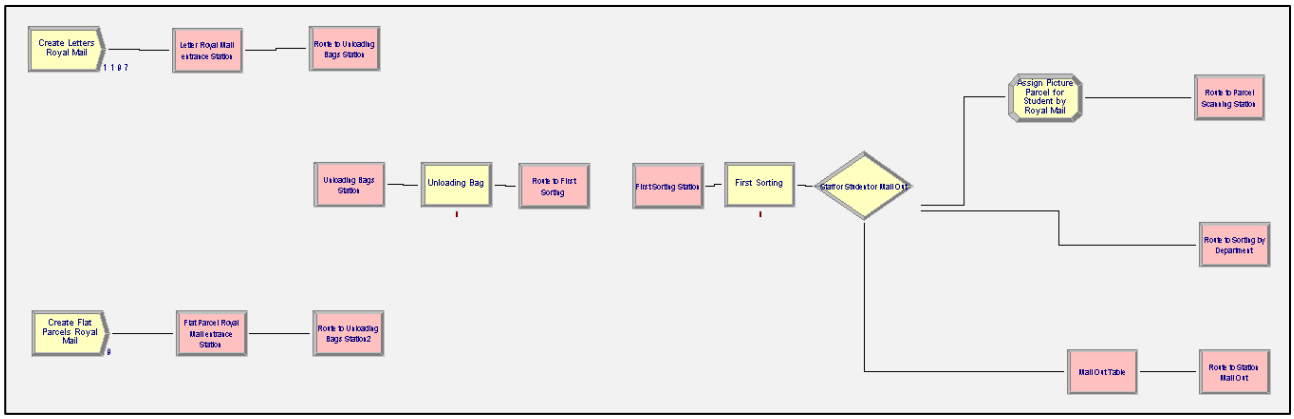


Figure 28 - Mail and Sorting Area

In the Mail and Sorting Area the Distribution Centre deals with mails and parcels delivered by Royal Mail two times per day, one at 8 am and the other at 10 am within bags with a capacity of about 300 letters. After the bags have been unloaded, the majority of letters are sorted and placed in the parcels area or in the pigeonholes for the second sorting. The remaining part is placed on a desk to be stamped and picked up by Royal Mail in the afternoon.

The process has been simulated using the following modules:

4.3.1 - Create Letters Royal Mail, Create Flat parcels Royal Mail

Letters from Royal Mail arrive with different distributions two times per day. The values of the expressions have been implemented in a schedule in order to specify the period of time in which the delivery happens.

The same procedure has been applied to the Create Module of the Flat Parcels that arrives during the same hours but with different distributions.

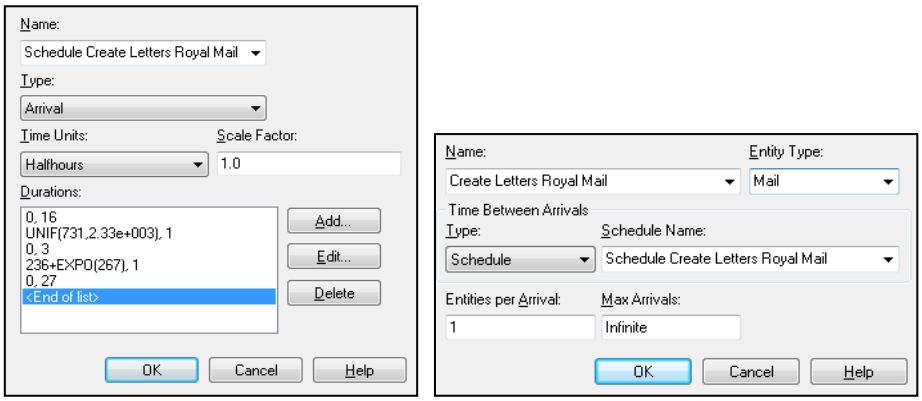


Figure 29 - Create Letters Royal Mail

4.3.2 - Unloading Bags:

The number of mails and delivered parcels by Royal Mail has been calculated on the average of the weight of the bag full of letters and that of each entity.

Weight of Bags (gr)	4000
Weight of a Mail (gr)	15
Weight of A4 Parcel (Marketing information, Circulars, Newsletters, Catalogues, Small Packages) (gr)	453.6
Maximum Mail contained in a bag (4000gr/15) (gr)	267
Maximum Parcels contained in a bag (4000gr/453.6) (gr)	15

Table 1 - Quantities of Letters and Parcels Inside Bags

After the Flat Parcels and Parcels' arrivals, they have to be unloaded from the bags; in this process two employees work together taking at least ten parcels per time. For this reason, a Set in the Unloading Bags process has been preferred with Quantity 0.1 to specify that 10 entities have to be processed by one resource per time.

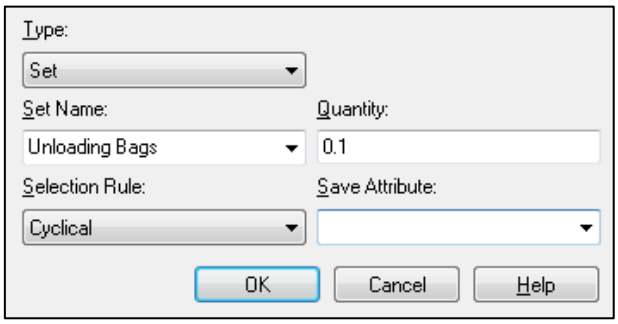


Figure 30 - Unloading Bags Set Logic

The process to transfer the letters from the bag to the desk takes few minutes and the distribution has been put in the expression field of the process module in the form of variable.

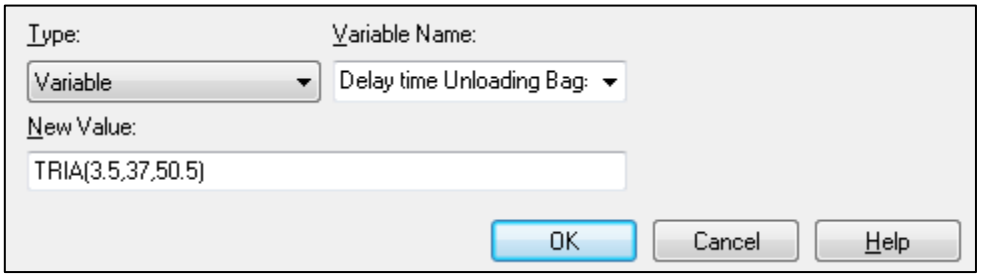


Figure 31 - Unloading Bags Random Distribution

4.3.3 - First Sorting

The First sorting is the process of separating the parcels according to their destination. Two workers inspect the letters and place them in the pigeonholes, or in the parcels area, or on the desk for the mails that have to be stamped. Also in this process the distribution is represented by a variable in the expression field.

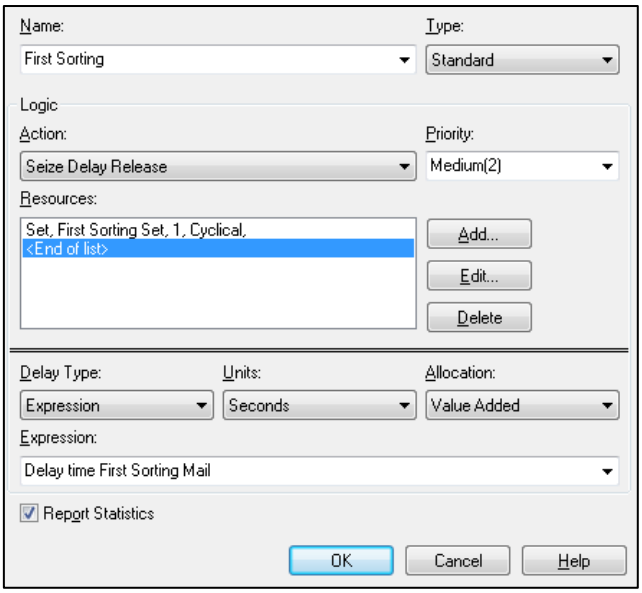


Figure 32 - First Sorting Process Setup

The Delay Time First Sorting Distribution it has been defined as: 0.5+EXPO(5.04)

4.3.4 - Staff or Student or Mail Out

A Decide Module has been used in order to specify the percentage of letters intended to the three different areas. It has been observed that the majority of parcels delivered by Royal Mail are put in the pigeonholes to be delivered to students; the 31% is destined to the staff and the remaining part to the stamping process. Hence, based on an average of percentages for each day and for each delivery, the rates calculated have been displayed in the Chances of the decide module:

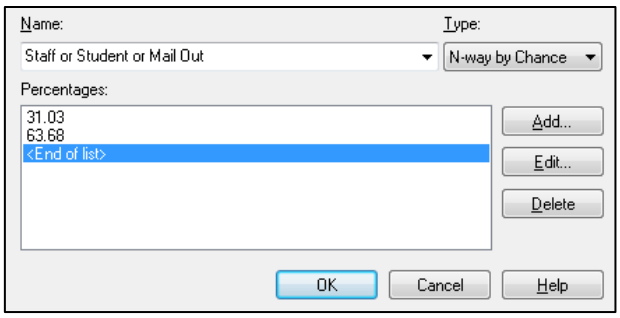


Figure 33 - Staff or Student or Mail Out

From this module the entities follow different paths as mentioned before and they have been sent to the specified destination using stations and routes in which is specified the arriving station.

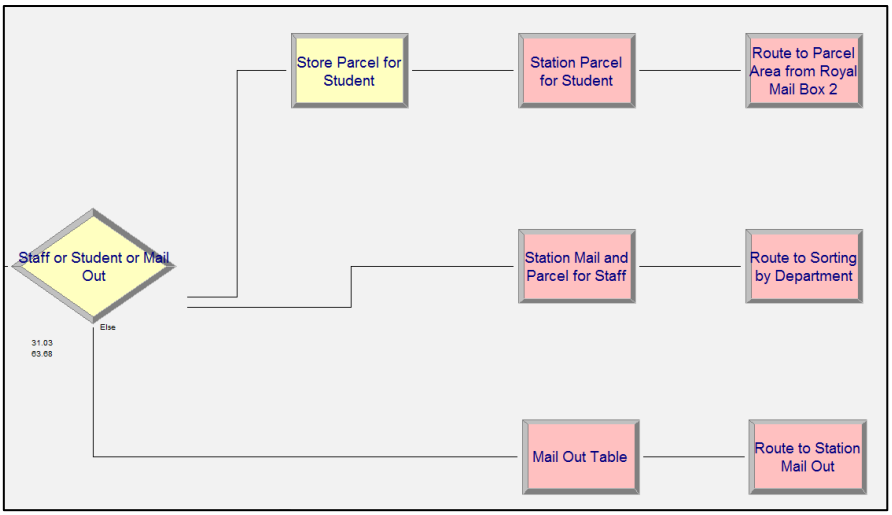


Figure 34 - Student or Staff Mail-Out possible Outcomes

4.4 - Parcels Area (Royal Mail for DC)

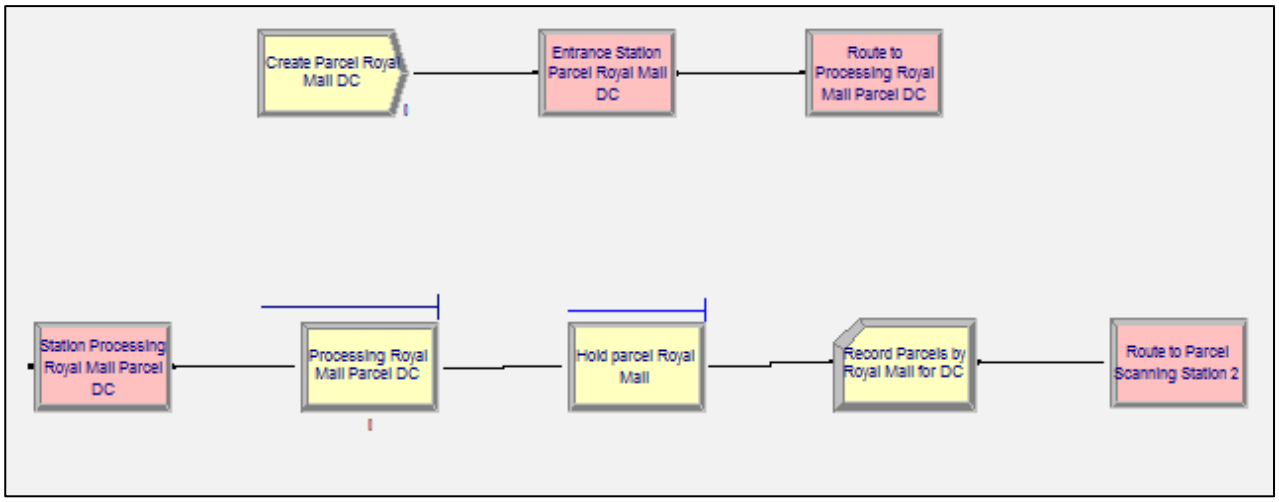


Figure 35 - Parcels Area from Royal Mail for Distribution

Royal Mail also delivers parcels intended for the Distribution Centre that do not have to be sorted and are placed on the desk of the parcels' area. When one of the resources involved in that area is idle, they are scanned and stored as the parcels delivered from couriers.

4.4.1 - Create Parcel Royal Mail DC

Parcels arrive with two different distributions two times per day. To specify the hours in which parcels are delivered, the type Schedule has been chosen in the Create module and the expressions have been initialised with the following values at 8 am and at 11am, with duration of a half-hour:

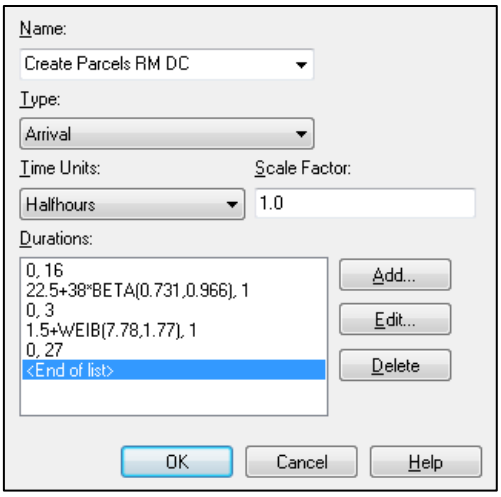


Figure 36 - Schedule for Parcels from Royal Mail Creation

4.4.2 - Processing Royal Mail Parcel DC

The parcels are transferred to the desk of the parcels area to be scanned.

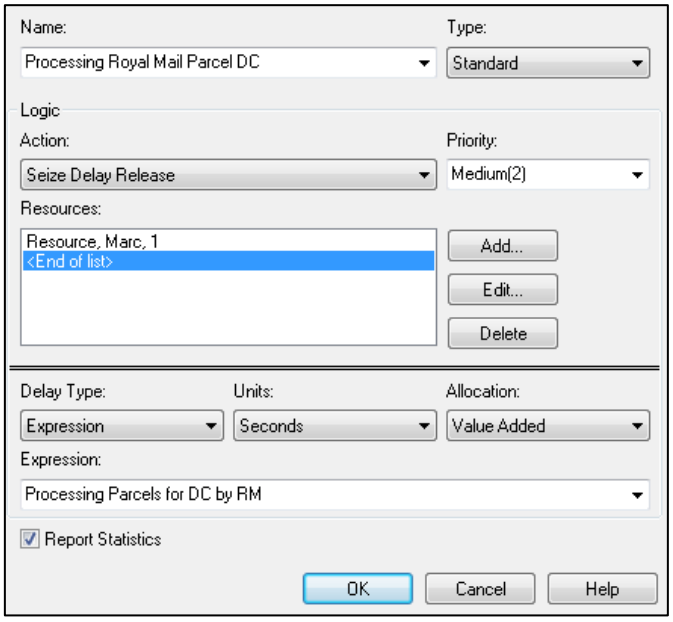


Figure 37 - Royal Mail for DC Process Module

Each parcel delivered by Royal Mail will be processed according to the distribution contained in the Expression field's variable:

$$1.5 + 8 * \text{BETA}(1.36, 1.74)$$

4.4.3 - Hold Parcels Royal Mail

While the parcels have to be scanned and then stored, they have to wait that one of the resources that works in the parcels area become available. To let them wait, a Hold module has been linked to the route to parcels area with the condition:

STATE(Amanda) == BUSY_RES || STATE(Jack) == BUSY_RES

4.5 - Mail and Parcel for Staff Area

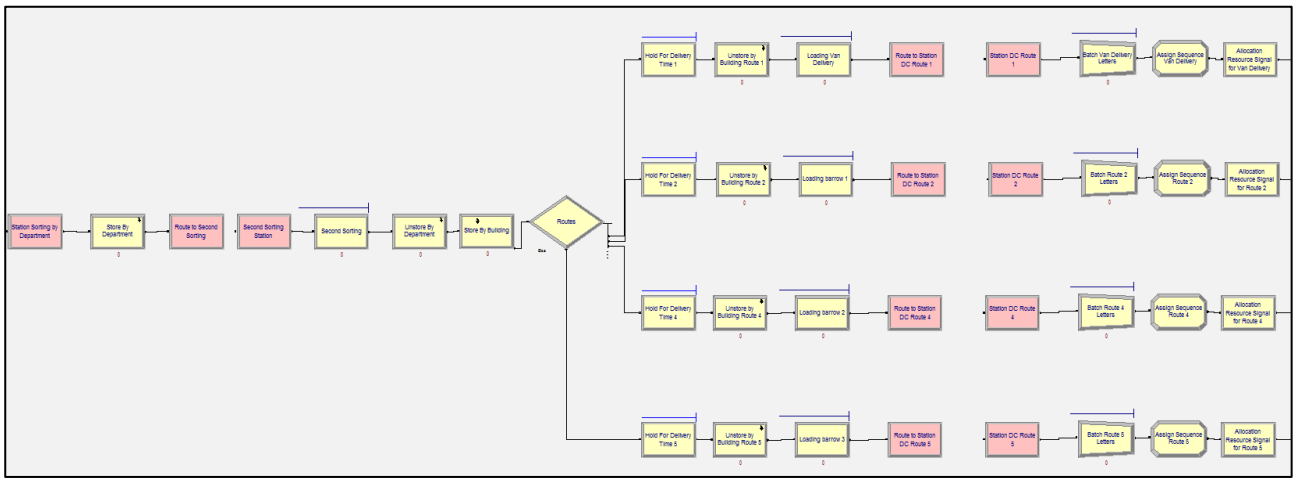


Figure 38 - Mail and Parcel for Staff Area

All the mail that has been gone through the first sorting is routed in this area represented by its initial station “Station Sorting by Department”. This area and its processes can be roughly divided in two parts where one is conducted inside the Distribution centre and the other is related to the delivery of mail throughout the campus. The first part (Figure 38) will be then analysed. With the first sorting all the letters and flat parcels present in the mail bags are sorted by department and therefore placed in the relative box (Figure 39). The “Store by Department” sub-model in fact represents each wooden box that exists in the sorting shelf.

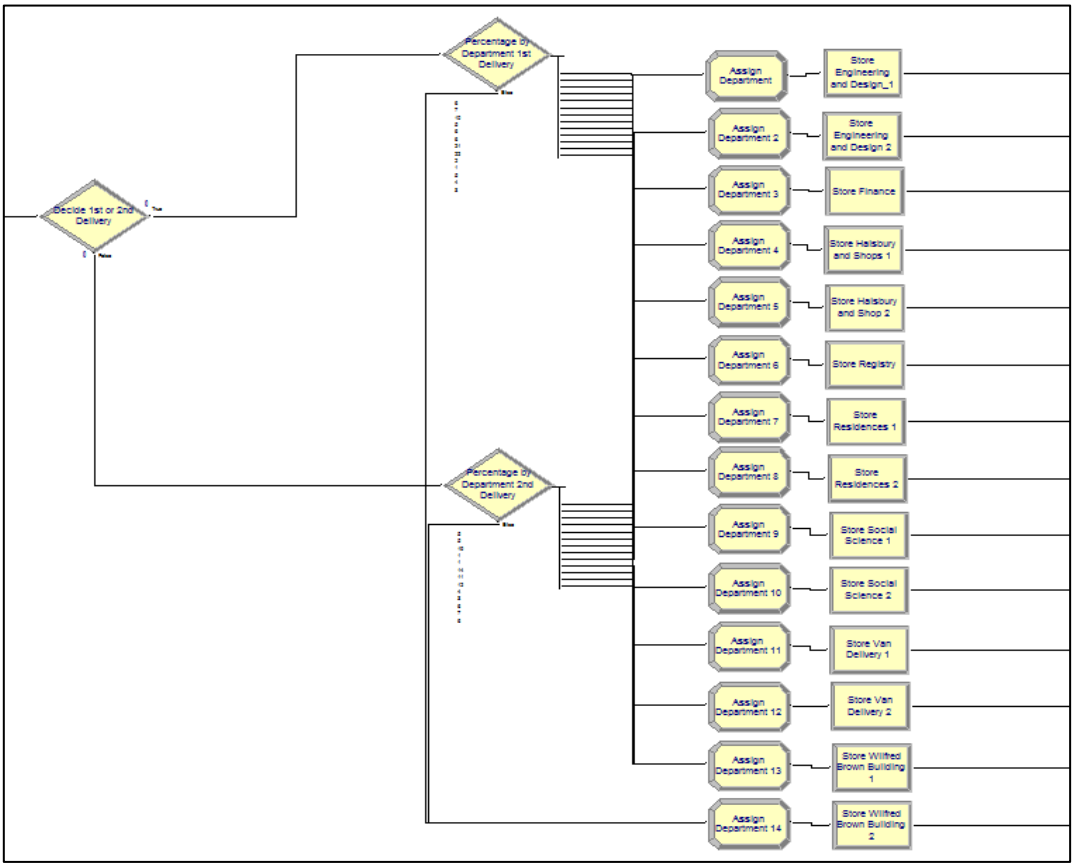


Figure 39 - Store by Department

Inside the sub-model the entities will first undergo to a decide module called “Decide 1st and 2nd Delivery” (Figure 40). Here the letters that are delivered in the morning (CalHour(TNOW) < 9)) are routed through the True exit of the module whereas the ones arriving in the afternoon through the else exit.

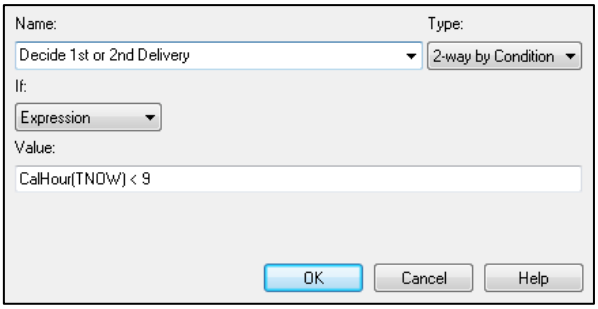


Figure 40 - 1st and2nd Delivery Decide Module

When the entities are convoyed in either the former or the latter exit, each of them will encounter another decide module (Figure 41) that, according to the chance percentage relative to the collected data, will route the arrived letters in various assign modules (one for each “pigeonhole”).

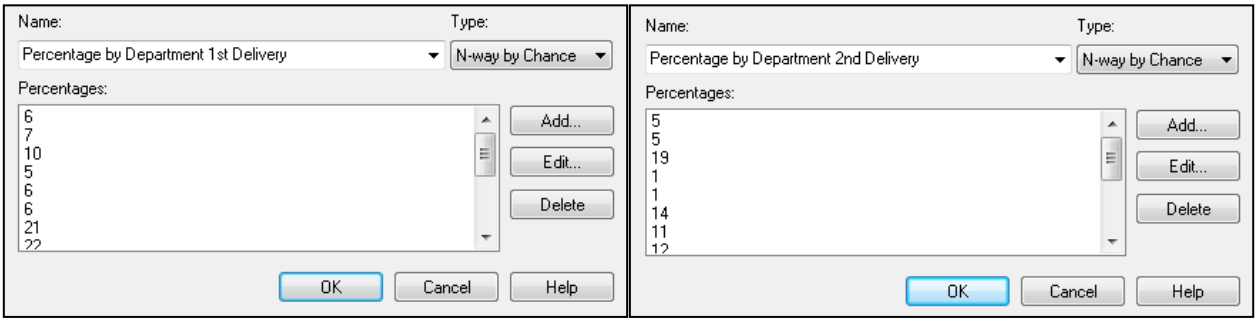


Figure 41 - Percentage by Department 1st and 2nd Delivery

Each assign module (Figure 42) contains an attribute with a value that, assigned to the entity, will be useful in the next stages in order to unstore and place the letters in the right delivery route.

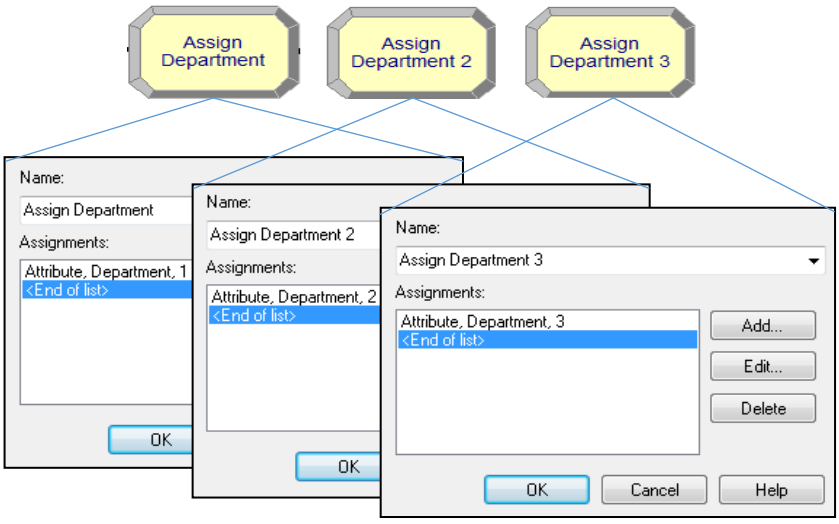


Figure 42 - Assign Modules for Each Department

Once stored the letters can continue in the model logic and undertake another sorting process.

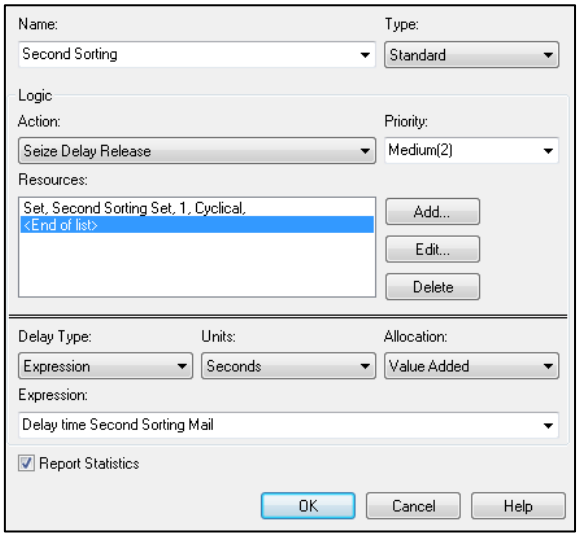


Figure 43 - Second Sorting Process Module

In the second sorting process, the letters are handled by whoever is idle in the selected set at the moment of the entity arrival (Igor, Michael, Andreas or Kevin) according to the selected cyclical rule (Figure x). Its distribution is equal to: 0.5+15*BETA(5.52,20.6)

The second sorting consists in more or less the same procedure as the first but instead of divide the letters by department; they will be divided by building per department. In fact, once unstored from the previous location, the entities enter another store sub-model called “Store by Building”.

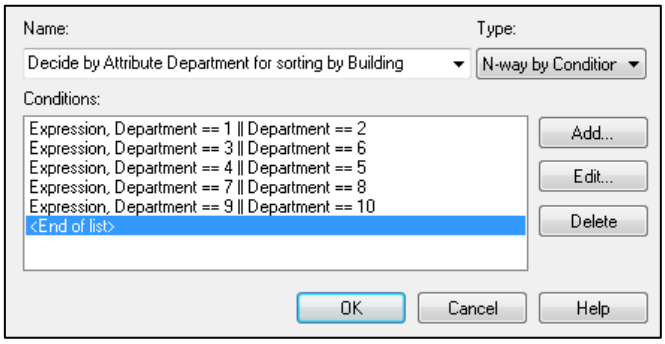


Figure 44 - Decide by Attribute Department for sorting by Building

A decide module will first conduct the entities in its specific area using the attributes previously assigned (Figure 44) where other decide module per department will split the entities by building following the n-way by chance rule.

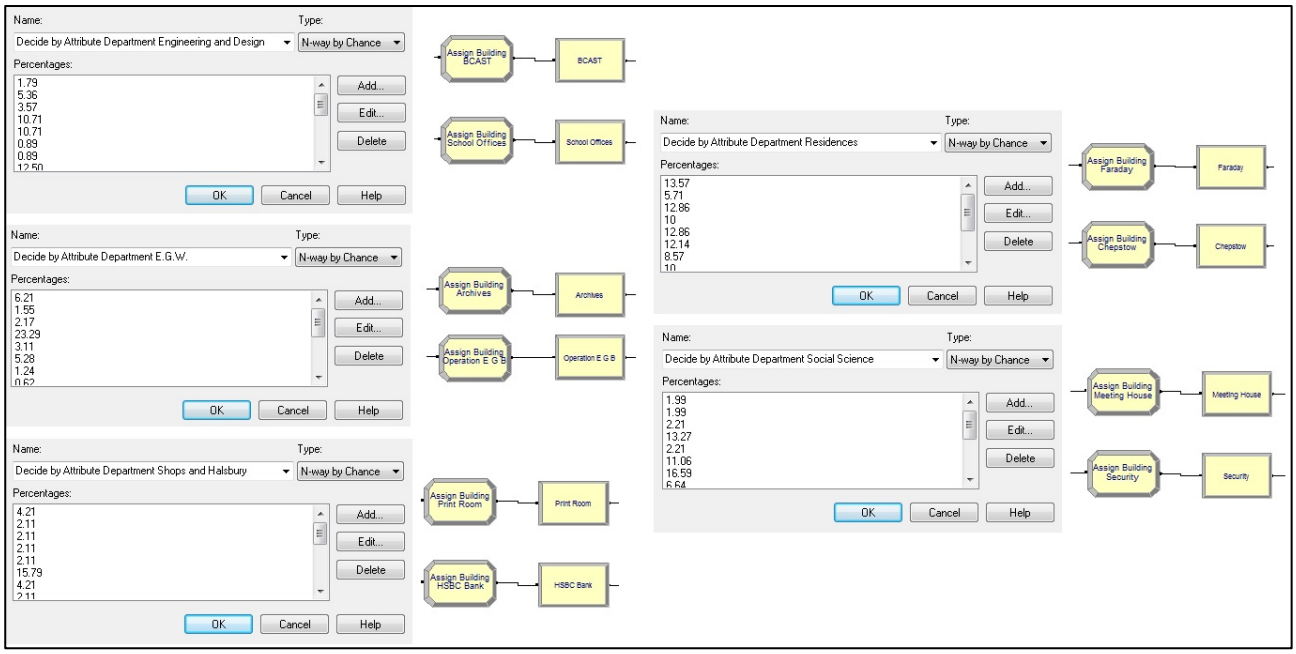


Figure 45 – Sub-model's Assign And Decide Modules

Figure 45 shows a sample of the multiple assign and store modules that can be found in the sub-model mentioned before. With the n-way by chance type selected and its relative percentages, the entities receive an assignment according to which exit they went through and get stored in the metal "pigeonholes". They now really represent the mail that each building receives every day.

The entities further proceed through the module and they now need to be divided into 4 main streams which they will subsequently represent the actual delivery mail routes executed by the distribution centre employees. For this reason a decide module has been used, basing it and the recall of all the assigned building attributes as Figure 46 shows.

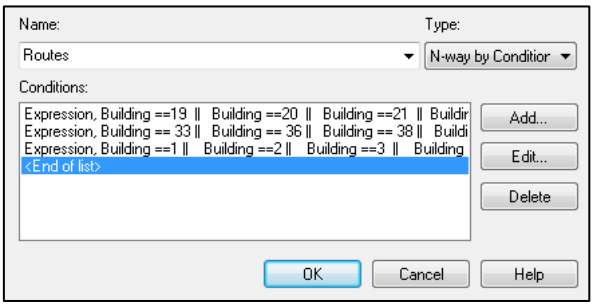


Figure 46 - Routed Defining Decide Module

The 4 main streams of entities shown in Figure 47, or letters, present exactly the same denotation with slight differences.

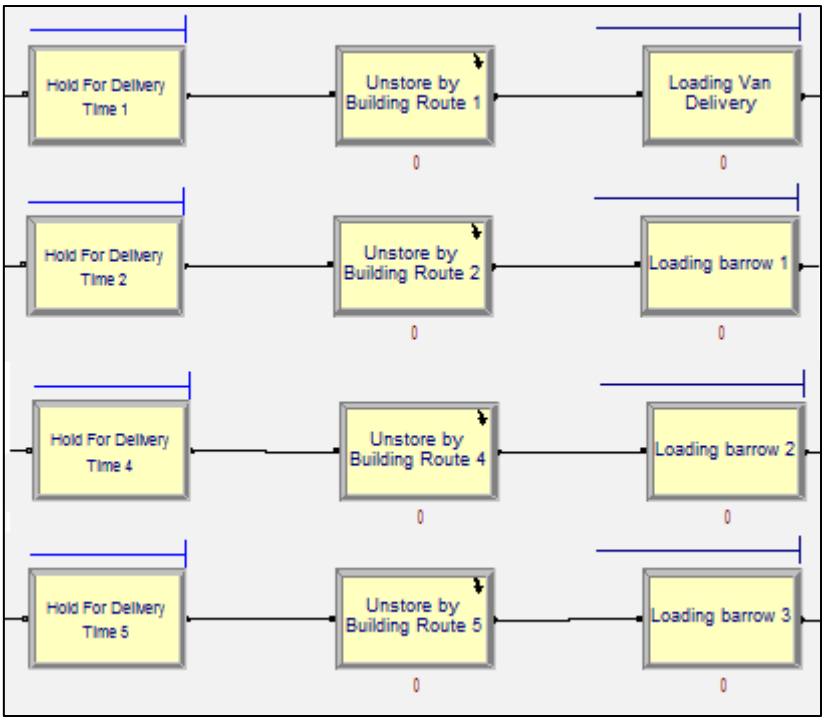


Figure 47 - Hold Modules Used to Schedule Mail Deliveries

The first route is relative to the delivery of mail through the use of the van. Since the van delivery presents a daily fixed schedule where it performs its mail distribution only at 11am, the hold module has been set up so that the entities are processed at the right time (Figure 48).

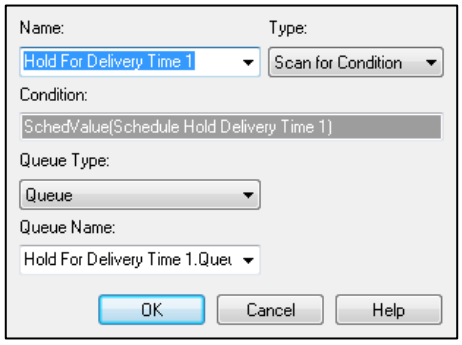


Figure 48 - Hold for Delivery General Setup

The scan by condition allows reading the specific schedule created for this particular route: when the TNOW reaches the wanted value, the entities can be started to be processed in the “Loading Van Delivery” process module. For the intrinsic act of moving an entity from one place to another while loading the vehicle, all the letters pass through the unstore module “Unstore by Building Route 1” which represent the physical transition of every single envelope.

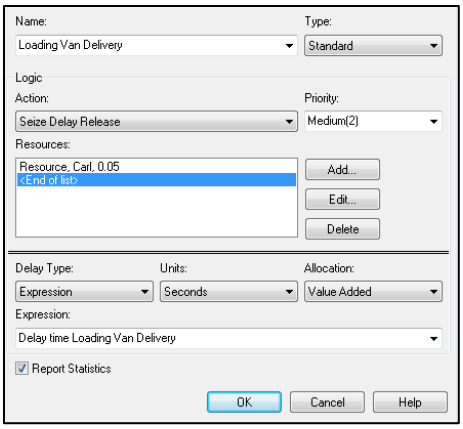


Figure 49 - Loading Van Delivery Process

The arriving entities are processed by the resource Carl. As it can be seen from Figure 49, every entity seize just 0.05% of the resource: this has been done in order to simulate properly the actual action of loading the van. When this operation has started, the employee collects a pile of 20 letters in order to place them in the vehicle's boot. Every stack of letters is processed according to the distribution in seconds "Delay Time Loading Van Delivery" which is defined as:

NORM(18.4, 5.62)

As said before, the same rules apply for the remaining three routes but with some important changes.

Firstly on the contrary from the van, the mail delivered through the use of barrows is scheduled twice per day: for this reason a different schedule has been applied in the Hold Modules' scanning condition field (Figure 50) with one delivery at 9.00am and one at 11.00am which follow the Royal Mail arrivals. The same Schedule has been therefore used since the 3 barrows start to load at the same time

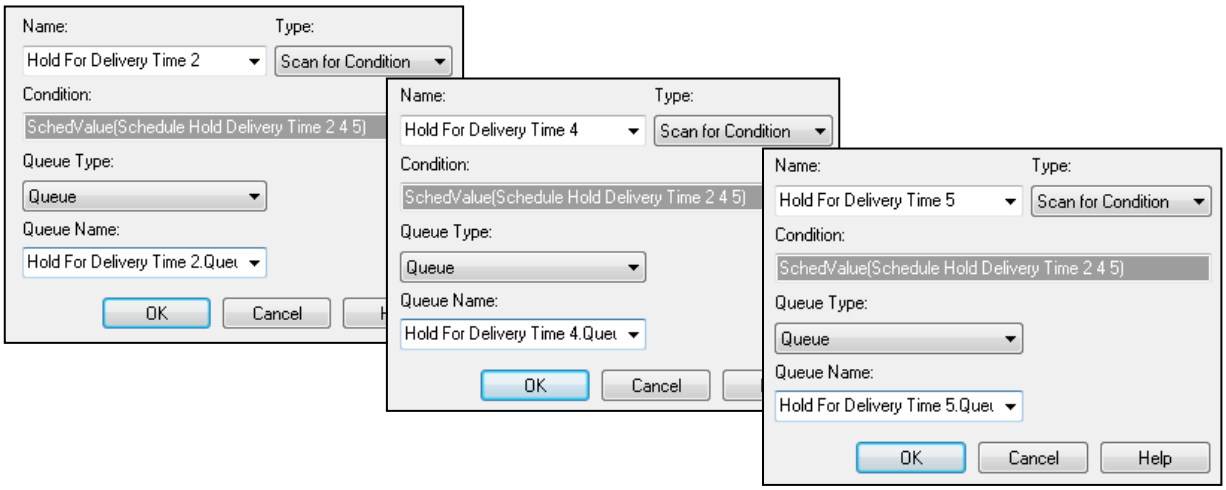


Figure 50 - Hold for Deliveries Setup

Once again, at the scheduled TNOW time, the condition will become true and the entities can move on to the next modules. With a different resource assigned to each route's process (Figure 51), the entities are processed in groups of 20 following the same "Delay time Loading Barrows" distribution which states in seconds: POIS(6.48)

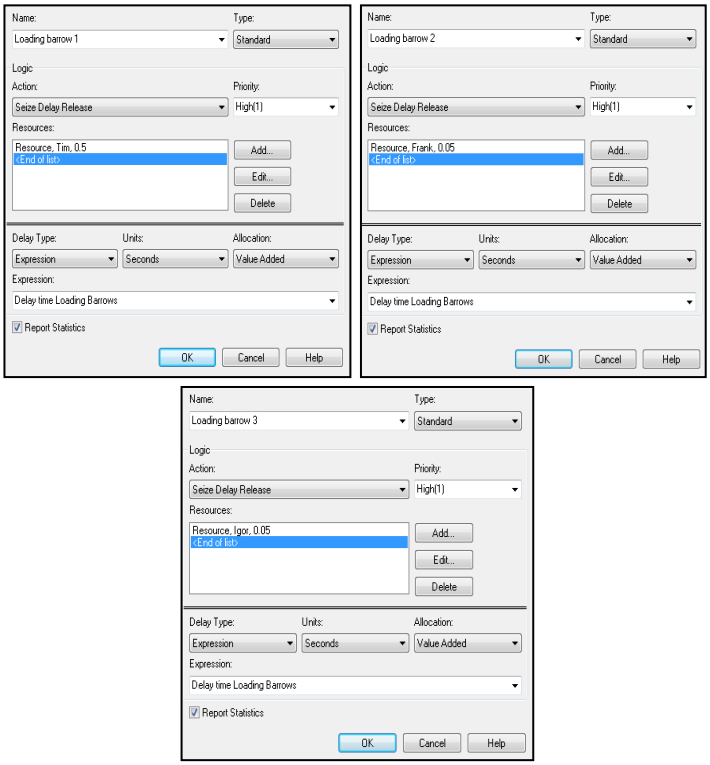


Figure 51 - Loading Barrows Process Modules

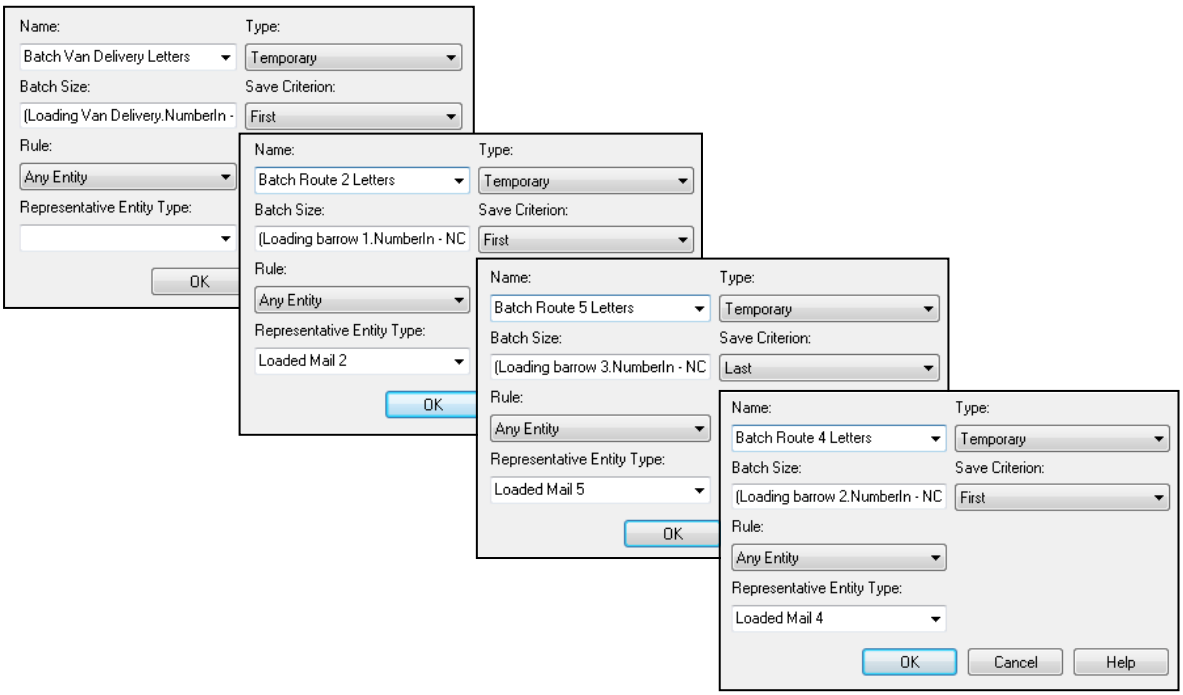


Figure 52 - Batch Modules for each Route

All the letters that have been processed, proceeding through the model, encounter then a batch module. This module provides a mechanism of grouping multiple entities into a single one which, according to the defined set up, can be temporary or permanent.

Figure 52 shows how these modules (one for each route) have been set up: the batched single entity will assume a temporary function for a part of the model while the batch size changes accordingly to the arrived mail day by day. With the size option it is possible to set a fixed number of the wanted batched entities: as a result, they will be placed in the relative module's queue until that number is reached and when, then, the batching process can start.

In the specific case of the Distribution Centre a random number, that refers to the arrived mail received at the scheduled times, was needed in order to better represent the loading process. For this reason the following equations have been used:

- **Batch van Delivery Letters**: (Loading Van Delivery.NumberIn - NC(Record Delivered Mail in Van Delivery Route))
- **Batch Route 2 Letters**: (Loading barrow 1.NumberIn - NC(Record Delivered Mail in Halsbury Route))
- **Batch Route 4 Letters**: (Loading barrow 2.NumberIn - NC(Record Delivered Mail in Engineering and Design Route))
- **Batch Route 5 Letters**: (Loading barrow 3.NumberIn - NC(Record Delivered Mail in Shops Route))

In order to generate these random batch sizes, the numbers of entities that enter inside the four Loading Processes have been used. Since the model is set to run for a complete month in a single repetition, using the "NumberIn" only would guarantee the correct batch size just for the first deliver because of it being cumulative until the next repetition when it is reset. To avoid this problem, the "NumberIn" has been subtracted with the values of the record modules situated at the end of each route's modules stream.

Considering that these numbers are always one round of mail behind the process modules, they represent a feasible way in order to manually adjust the batch sizes accordingly to the mail delivered at that specific time and avoiding the cumulating values. When all the available letters and flat parcels have transformed into a single temporary entity, they go ahead and go through an assign module (Figure 53).

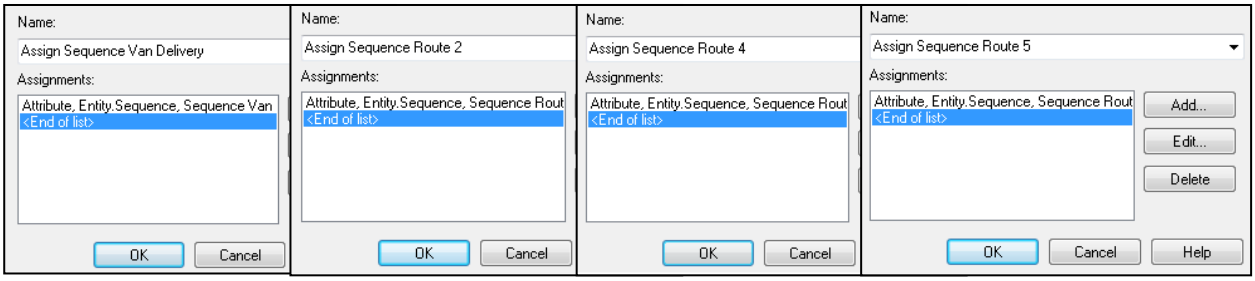


Figure 53 - Assign Sequences to Batch Entities

This block is used in order to allocate a sequence attribute to each entity that is going to be used to define every single delivery route with a transporter.

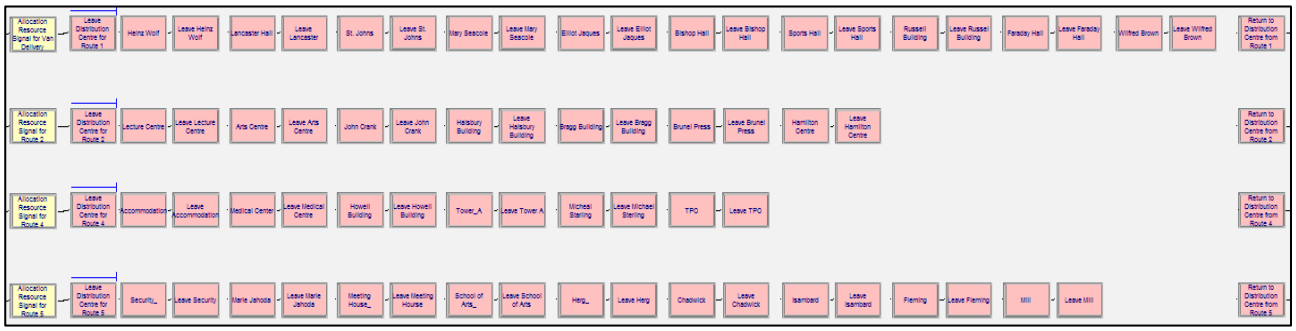


Figure 54 - Mail and Parcels for Staff Area's Transporters Logic

As previously mentioned the second part (Figure 54) of the Mail and Parcel for Staff Area concerns the actual transportation of mail throughout Brunel University's campus: the vehicles used for this purpose then leaves the DC premises and start to follow a specific path which follows the scheduled Mail Routes.

After have passed through the signal module (which has the purpose of bind the resource assigned to the delivery of letters through the use of a simple logic which will be explained after) the batch entities can enter the Leave modules. An example is given in Figure 55.

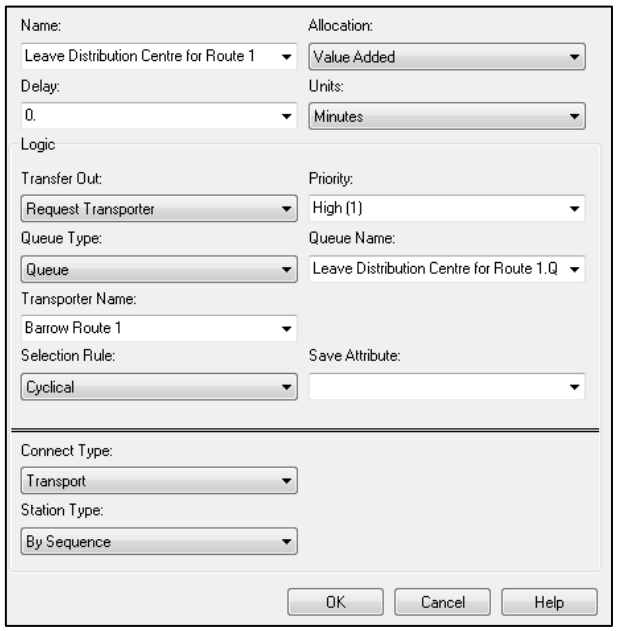


Figure 55 - Leave Module for Route 1

The four leave modules present a request transporter Transfer Out logic with each of them set on a specific transporter (Figure 56). Their maximum capacity was set to a factitious number (1000) that will be never reached, and each of them follows the sequence of stations (Departments' buildings) according to the defined distances and velocities (all the input distances and velocities can be found in the data collection booklet in the appendix).

	Name	Number of Units	Type	Distance Set	Velocity	Units	Initial Position Status	Report Statistics
1	Barrow Route 4	1000	Free Path	Barrow Route 4.Distance	33	Per Minute	1 rows	☑
2	Barrow Route 1	1000	Free Path	Barrow Route 1.Distance	36	Per Minute	1 rows	☑
3	Barrow Route 5	1000	Free Path	Barrow Route 5.Distance	21	Per Minute	1 rows	☑
4	Barrow Route 2	1000	Free Path	Barrow Route 2.Distance	36	Per Minute	1 rows	☑

Figure 56 - Available Transporters

Being set as "By Sequence" in the station type of the Leave Modules, the transporters will start moving from the Distribution Centre Station and it will follow the sequences that were previously assigned (Figure 57). The velocity and the distances (Figure 56 and 57 accordingly) will define the time that it is needed to deliver the all the mail and go back to the Distribution Centre.

	Station Name
1	Heinz Wolf Station
2	Lancaster Hall Station
3	St. Johns Station
4	Mary Seacole Station
5	Elliot Jaques Station
6	Bishop Hall Station
7	Sports Hall Station
8	Russell Building Station
9	Faraday Hall Station
10	Wilfred Brown Station
11	Return to Distribution Centre from Route 1.Station

	Beginning Station	Ending Station	Distance
1	Station DC Route 1	Heinz Wolf Station	526
2	Heinz Wolf Station	Lancaster Hall Station	377
3	Lancaster Hall Station	St. Johns Station	308
4	St. Johns Station	Mary Seacole Station	329
5	Mary Seacole Station	Elliot Jaques Station	448
6	Elliot Jaques Station	Bishop Hall Station	318
7	Bishop Hall Station	Sports Hall Station	90
8	Sports Hall Station	Russell Building Station	279
9	Russell Building Station	Faraday Hall Station	231
10	Faraday Hall Station	Wilfred Brown Station	603
11	Wilfred Brown Station	Return to Distribution Centre from Route	1
12	Return to Distribution Centre from Route 1.Station	Station DC Route 1	374
13	Station DC Route 1	Leave Distribution Centre for Route 1.Station	1

	Station Name
1	Lecture Centre Station
2	Arts Centre Station
3	John Crank Station
4	Halsbury Building Station
5	Bragg Building Station
6	Brunel Press Station
7	Hamilton Centre Station
8	Return to Distribution Centre from Route 2.Station

	Beginning Station	Ending Station	Distance
1	Station DC Route 2	Lecture Centre Station	292
2	Lecture Centre Station	Arts Centre Station	64
3	Arts Centre Station	John Crank Station	103
4	John Crank Station	Halsbury Building Station	196
5	Halsbury Building Station	Bragg Building Station	99
6	Bragg Building Station	Brunel Press Station	110
7	Brunel Press Station	Hamilton Centre Station	103
8	Hamilton Centre Station	Station DC Route 2	376
9	Station DC Route 2	Leave Distribution Centre for Route 2.Station	1
10	Hamilton Centre Station	Return to Distribution Centre from Route	1

	Station Name
1	Accommodation Station
2	Medical Center Station
3	Howell Building Station
4	Tower A Station
5	Micheal Starling Station
6	TPO Station
7	Return to Distribution Centre from Route 4.Station

	Beginning Station	Ending Station	Distance
1	Station DC Route 4	Accommodation Station	226
2	Accommodation Station	Medical Center Station	40
3	Medical Center Station	Howell Building Station	156
4	Howell Building Station	Tower A Station	142
5	Tower A Station	Micheal Starling Station	196
6	Micheal Starling Station	TPO Station	20
7	TPO Station	Station DC Route 4	294
8	Station DC Route 4	Leave Distribution Centre for Route 4.Station	1
9	TPO Station	Return to Distribution Centre from Route	1

	Station Name
1	Security Station
2	Marie Jahoda Station
3	Meeting House Station
4	School of Arts Station
5	Herg Station
6	Chadwick Station
7	Isambard Station
8	Fleming Station
9	Mill Station
10	Return to Distribution Centre from Route 5.Station

	Beginning Station	Ending Station	Distance
1	Station DC Route 5	Security Station	210
2	Security Station	Marie Jahoda Station	163
3	Marie Jahoda Station	Meeting House Station	62
4	Meeting House Station	School of Arts Station	39
5	School of Arts Station	Herg Station	21
6	Herg Station	Chadwick Station	20
7	Chadwick Station	Isambard Station	13
8	Isambard Station	Fleming Station	32
9	Fleming Station	Mill Station	26
10	Mill Station	Station DC Route 5	470
11	Station DC Route 5	Leave Distribution Centre for Route 5.Station	1
12	Mill Station	Return to Distribution Centre from Route	1

Figure 57 - Sequences and Their Relative Distances

Each building is represented by a station and to allow the entity to go in the correct next station, they are followed by Leave modules that, referring to the sequence, will idicate the right one without releasing the seazed transporter.

When the last building for each route is reached, the final Enter modules will allow the transporter to be released and go back to the Distribution Centre.

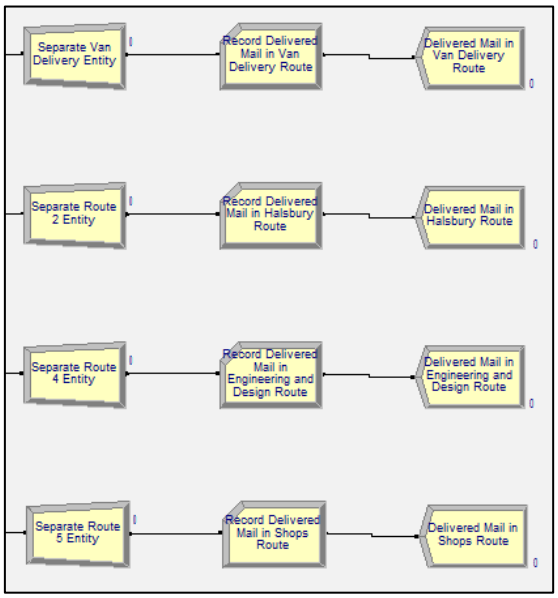


Figure 58 - Distribution Streams Separate, Record and Dispose Modules

The released entities, being carried by the transporters, continue the last part of the model logic undertaking the Separate Modules. Here, the previously batched entities will be split returning in their initial form and maintaining their attributes (Figure 59).

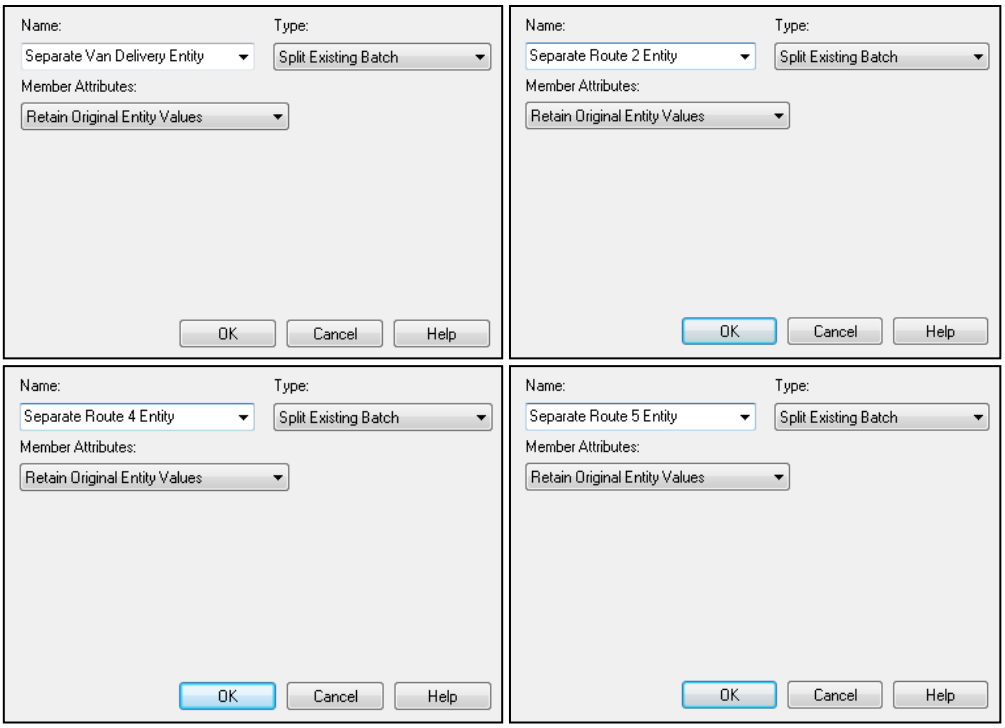


Figure 59 - Separate Modules

Once separated, the entities are then recorded and disposed out of the system.

4.6 - Busy Resources Logicfor Routes

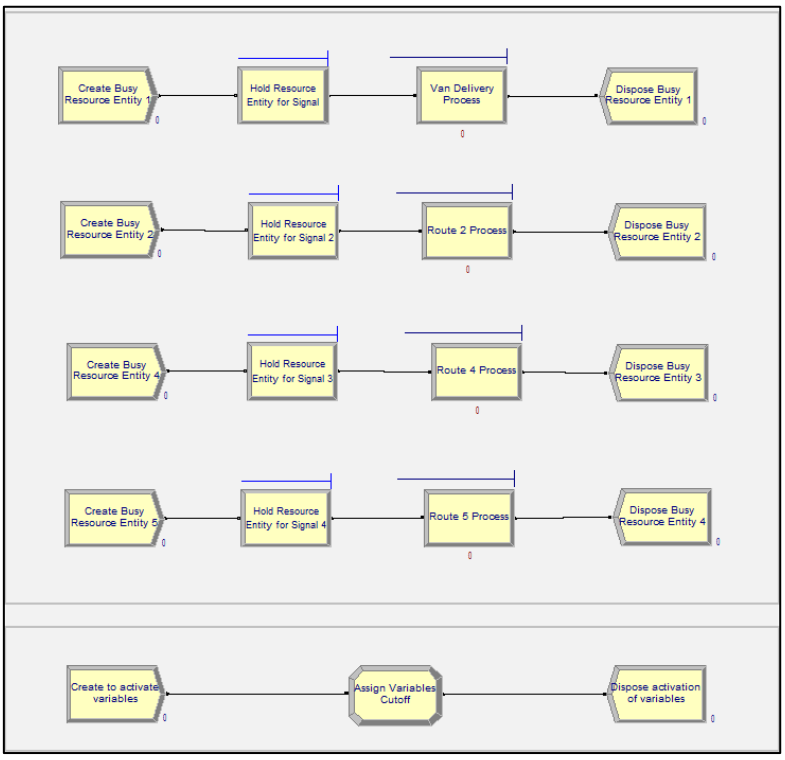


Figure 60 - Transporters' Busy Resource Logics

In order to make the resources assigned to the transporters busy, an independent model logic for each of them has been created. This is due to the fact that in the real system, as mentioned in the previous sections, an employee has the duty of deliver the mail with a vehicle (barrows or van) for every distribution mail. In the computerized model, these vehicles have been represented by transporters and in order to have a right utilization of the resources assigned to the delivery paths, these logics will create an entity at the right moment of delivery (specified inside the hold modules) which will busy the right employees for the exact time of the transporter completing one whole defined route.

4.6.1 - Create busy Resource for Van Delivery's Route

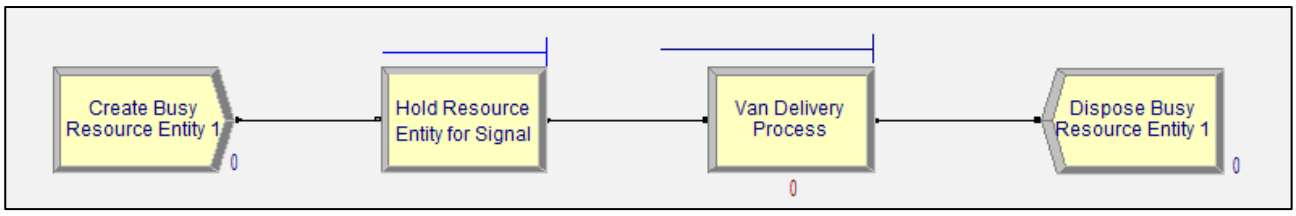


Figure 61: Create Busy Resource Entity 1 Module

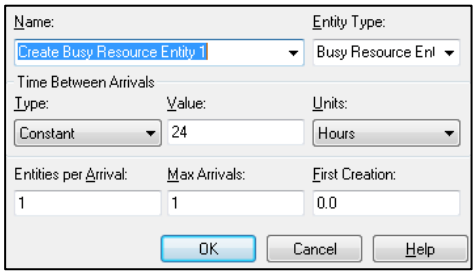


Figure 62 - Create Busy Resource Entity 1

This process has been created to allow the entity involved in the loading parcels and mail for the staff into the van delivery, after completing this task, will be the same to deliver the loaded staff, according to the assigned route. However, the following Hold module is linked to the Signal module in the *Station Mail and Parcel for staff area* and explains that as soon as the employee has finished the loading process, the Van Delivery round can start.

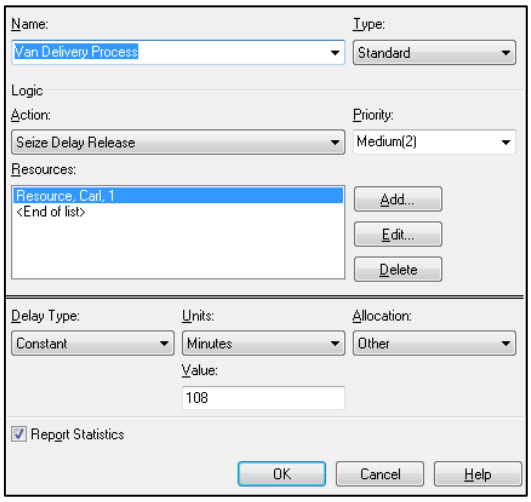


Figure 63 - Van Delivery process

The collected data have revealed that it takes 108 minutes to complete the whole Route 1. This explains the logic used to assign the Value in the Delay. Furthermore, as already specified, the same resource used for the Loading process will be the same for this process.

4.6.2 - Create busy Resource for Barrows' Route

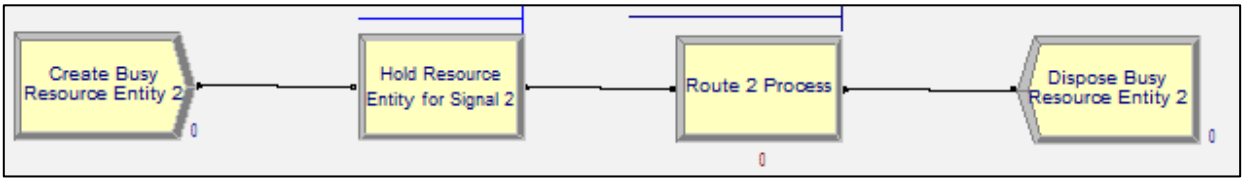


Figure 64 - Create Busy Resource Entity 2

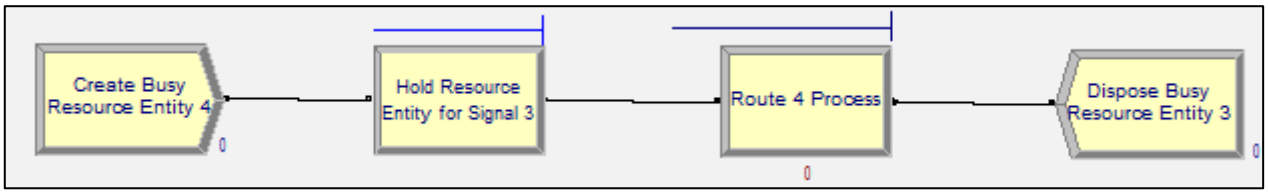


Figure 65 - Create Busy Resource Entity 4

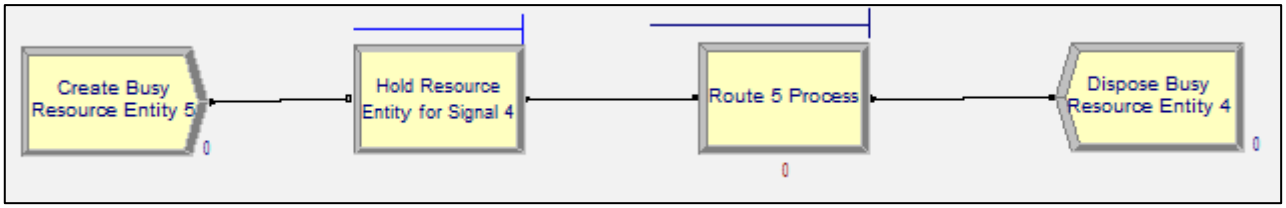


Figure 66 - Create Busy Resource Entity 5

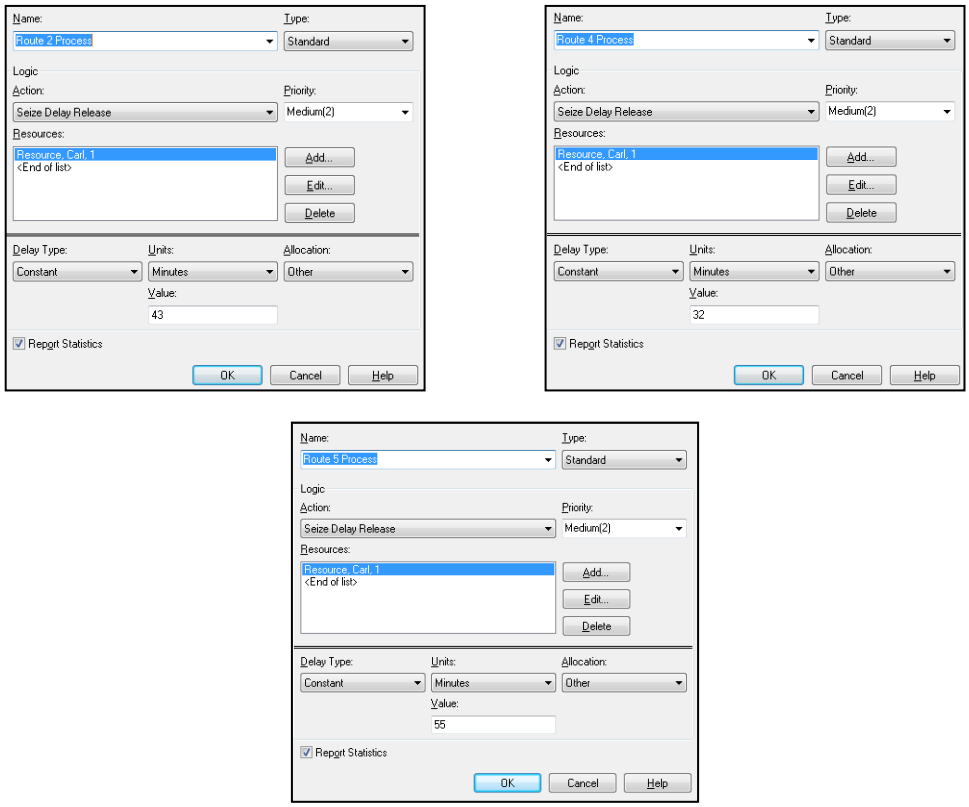


Figure 67 - Route 2, 4 and 5 Process Modules

The same logic as before has been used for the following processes, with the difference that the transporters used are three barrows instead of the Van. As a consequence, as can be predicted, the time necessary to complete the different Routes will take less minutes than before considering that three different employees (one for each barrow) will be spread among the closest destinations, reachable by foot.

4.7 - Create to activate variables

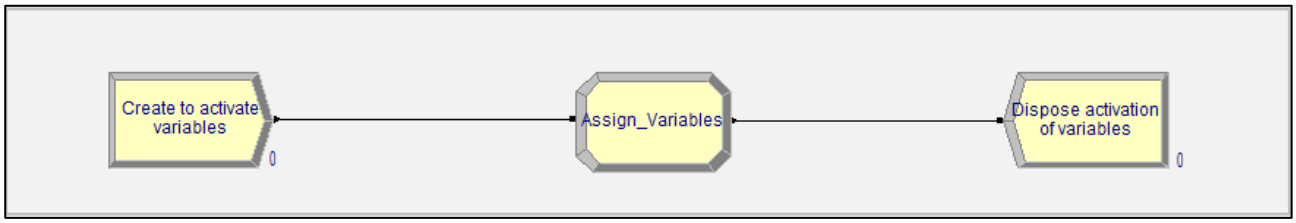


Figure 68 - Variable Activations Independent Logic

In the model developed so far, the entities created have represented physical object. However, in this case it has been considered useful to create a logical entity, whose role is to perform some logical or control task. In the current system, that logical entity has been created in order to specify that as soon as the first parcel enters the system, the all variables involved in the system will be assigned.

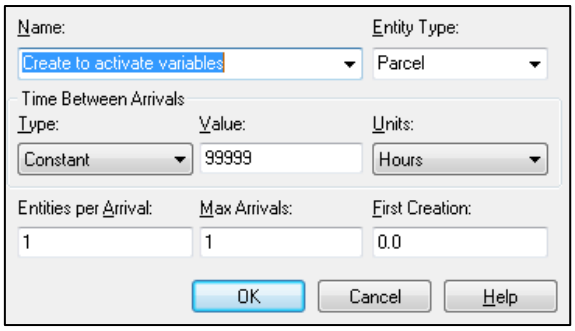


Figure 69 - Entity Create for Variables Activation

4.8 - Mail-Out Area

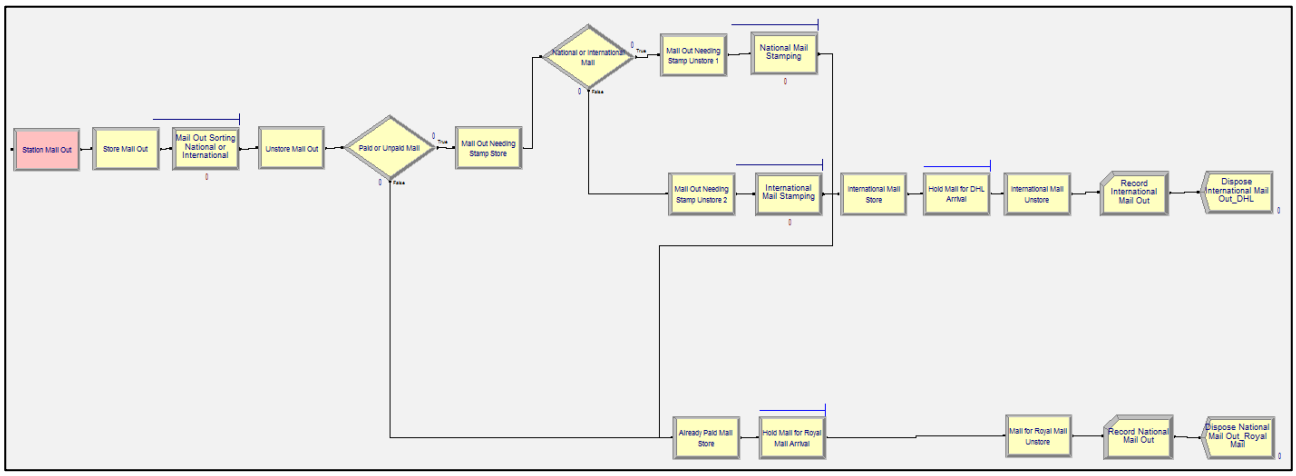


Figure 70 - Mail-Out Area

All the mail that needs to be sent from Brunel University's departments and offices to international and international destinations is here routed and stored in the appropriate space. Every letter is then sorted out in the first process module.

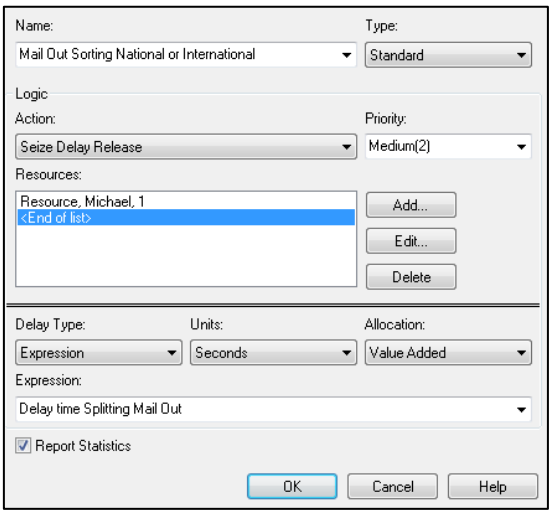


Figure 71 - Mail-Out Sorting Process

Each letter is processed by the resource Michael following a distribution defined by the variable (in seconds) Delay time Splitting Mail Out which is equal to:

NORM(3.27, 1.21)

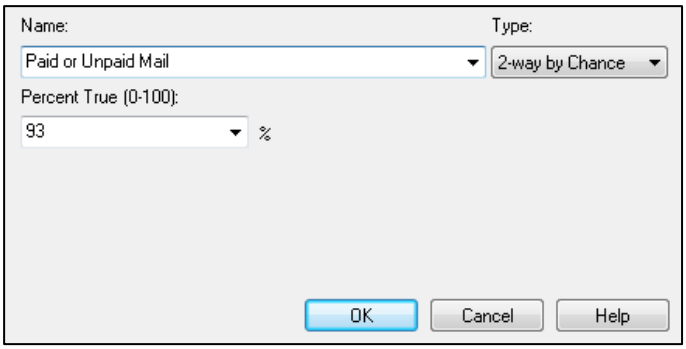


Figure 72 - Paid or Unpaid Decide Module

The next step in processing the Mail-Out is defined by understanding if the available letters already present a stamp or they need to be stamped. After have unstored the entities, the decide module divide the flow according to a 2 way by chance logic. Figure 72 shows that 93% of the letter delivered to the Distribution Centre necessitate to be stamped with the specific machines, while the remaining 7% can be send to storage in specific boxes.

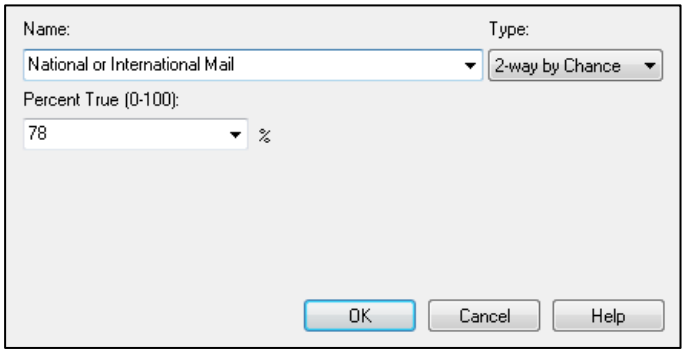


Figure 73 - Nation or International Mail Decide Module

Another decide (Figure 73) then defines the two paths that international or national mail can take. The former group, which represent the 78% of the totality, is brought to the Royal Mail certified machine where, one letter at a time, is processed and stamped (Figure 74) following the International Mail stamping distribution equals to: 0.5 + 10 * BETA(1.43, 1.75). The resources assigned to this process are Igor and the first member of the Stamping Machines set.

Once the Resource has finished applying the postal stamp to the letters, these get stored waiting for collection by the contracted courier (DHL).

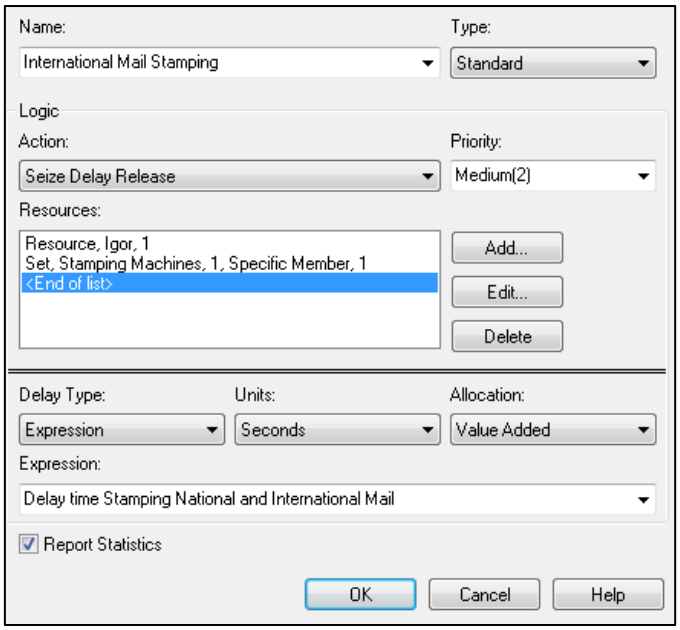


Figure 74 - International Mail Stamping Process

For this purpose the hold module has been used as the effective storage: its hold by condition allows holding all the processed entities until the scheduled DHL van usually arrive at the DC premises for collection. Therefore, as it can be seen from Figure 75, the letters will be hold until 2.00pm and then released, unstored, recorded and finally disposed out of the system.

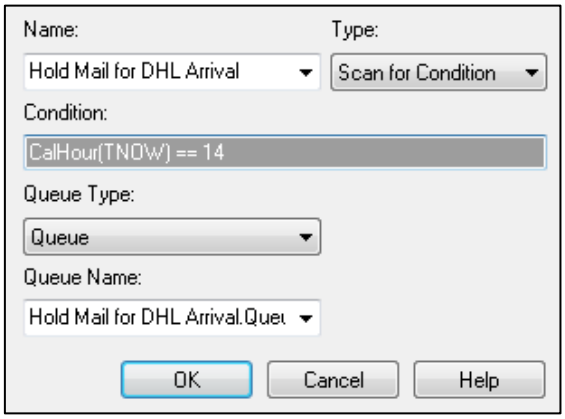


Figure 75 - Hold Mail for DHL Arrival

On the other hand, the National mail is stamped using the second machine but following the same procedure (hence the same distribution in Figure 76): once stamped by the same human resource and the second member of the same set, all the letters are kept in the relative box where they join the already paid mail that was previously processed.

This amount of mail will be hold (Figure 76) with the same logic as before and therefore they will be released at 2.00pm when the Royal Mail van is scheduled to come for collection.

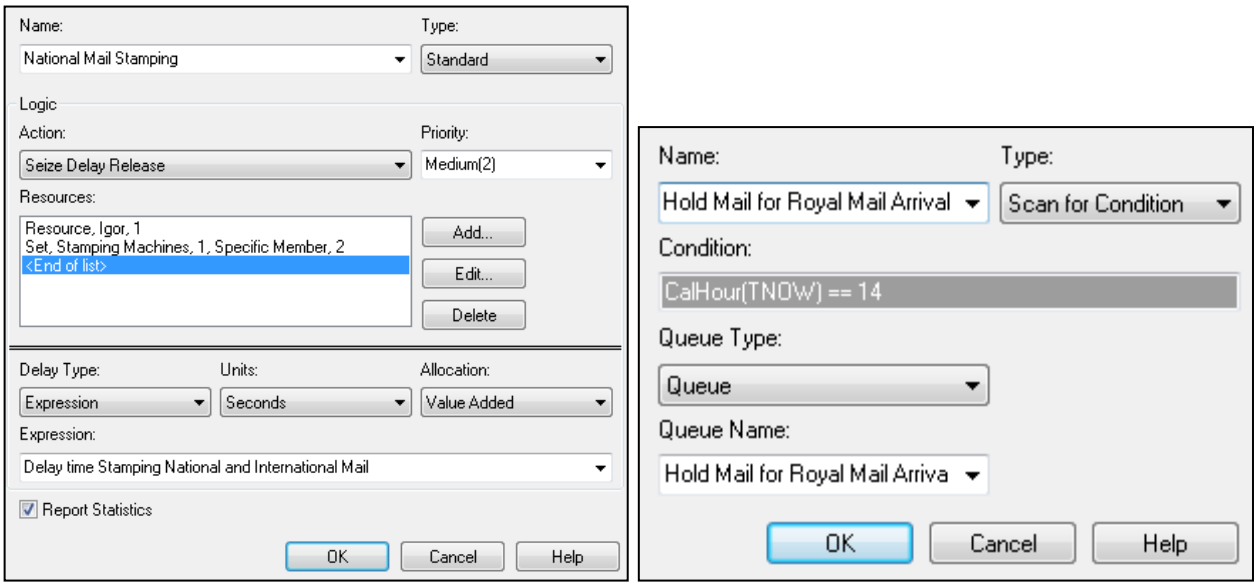


Figure 76 - National Mail Stamping Process and its Hold and Scan for Condition Module

The entities will then continue the model logic and therefore unstored, recorded and disposed.

RUN REPLICATION PARAMETERS

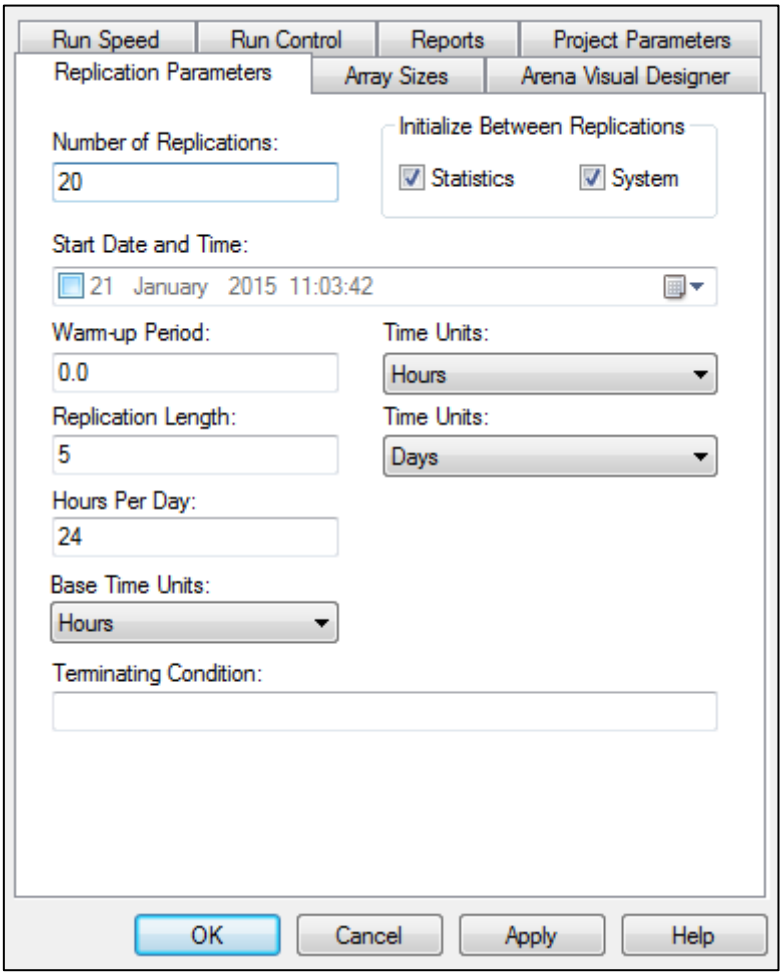


Figure 77 - Run Setup – Replication Parameters

The *Replication Length* of the simulation has been reproduced over a period of 5 days, considering the working days from Monday to Friday and has been put 20 as the Number of Replications in order to obtainsufficient information from the outcomes

The Date and Time field has not been filled to not associate a specific calendar date and time to simulation. In the Initialize Between Replications box, to collect new statistics after each replication, the *statistics* box has been selected and to throw away all the entities between one replication and another, the *System* option has been checked.

No *Warm-up Period* has been specified because no special initial conditions have to be reported. Even if the Distribution Centre works 8 hours per day, the section *Hours Per Day*has been filled with 24 since the working time has been specified in the schedules of each Create Module.

The *Base Time Units* selected is hours to report the outcomes in this time unit.

The confidence interval of the data is related to the number of iteration or replication *n*. In order to reduce the **half width** of the confidence interval of the output data the number of replication *n* has been increased.

The number of the *Record Customers* (Figure 78) has been used as analysis data to calculate the appropriate tolerance level. After five replications the sample mean is **576**. The half width of the **95%** confidence interval is **46.46** and it has been calculated as $\boldsymbol{t_{n-1,1-\alpha/2}\frac{s}{\sqrt{n}}}$.

Count	Average	Half Width	Minimum Average	Maximum Average
Record Customer	576.60	46.46	533.00	623.00

Figure 78 - Record Customers with 5 Replications

With the aim of at least halve the half width interval obtained with five replications, the replication themselves have to be increased. An easy way to find the tolerant level of *n* is proceed by iteration using the following formula: $\boldsymbol{n_0}$ is the number of the initial replications and $\boldsymbol{h_0}$ is the obtained half width (Kelton, et al., 2010).

$$n \cong n_0 \frac{h_0^2}{h^2}$$

In this case in order to reduce the number of $h_0 = 46.46$ to an expected value of 23 the number of replication has been calculated as follow:

$$n \cong 5 \frac{46.46^2}{23^2} = 20.4$$

Therefore, the necessary number of replication to achieve the expected result is **20**. However, using this replication number in has directed to a better value of Half Width equals to 11.66 for what concern the chosen variable (Figure 79).

Count	Average	Half Width	Minimum Average	Maximum Average
Record Customer	574.50	11.66	533.00	623.00

Figure 79 - Record Customer with 20 Replications

6.1 - Validation and Verification Background

When a simulated model has the purpose of being used to improve a system's performance, solve problems or aid the decision-making process related to it, it is important to understand if the results obtained through the virtual representation are reliable or not.

In order to verify if the model and its outcomes can be considered correct and statistically valid, it is necessary to make the computerized program undertake a process of validation and verification. Model Verification is concerned with building the module right: in fact, it has to ensure that the Arena modelled system, together with its implementations, is correct (program debugging). On the other hand, Validation ensures that the right model has been built: it is fundamental that it properly reflects the system in real life on which is based. This method usually uses an iterative process, whether discrepancies are found, in order to improve the accuracy of the model till acceptable levels.

The appropriate statistical test that has been used for the validation of our model is the ***t*-test,** through which it is possible to compare the actual difference between two means in relation to the variation in data (expressed as the standard deviation of the difference between the means). More specifically, because of the difference in the sample size (and having considered independent samples) a *two-sample t-test* has been used.

The following procedure has been adopted to validate the Arena's output data against the collected ones.

6.1.1 - Step 1: Specify the hypotheses

The hypothesis to be tested is:

- H_0 the model measure of performance = the system measure of performance
- H_α the measure of performance ≠ the measure of performance

Parameters of interest = μ_1 and μ_2

$$H_0 : \mu_1 - \mu_2 = c \quad \text{vs.} \quad H_a : \mu_1 - \mu_2 < c \quad \text{(lower-tail test)}$$

$$H_a : \mu_1 - \mu_2 > c \quad \text{(upper-tail test)}$$

$$H_a : \mu_1 - \mu_2 \neq c \quad \text{(two-sided test)}$$

The hypothesized difference in the means is *c.*Usually this value is equal to 0 and simplifies the hypotheses above.

6.1.2 - Step 2: Choose a level of significance α=0.05

6.1.3 - Step 3: Compute the test statistic (on the basis that σ_1 and σ_2 are unknown and may not be the same).

The test statistic is:

$$t_{obs} = \frac{(\bar{x}_1 - \bar{x}_2) - c}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Then this test statistic will have a t-distribution with the following degree of freedom:

$$\text{df} = \frac{\left[(SE_1)^2 + (SE_2)^2\right]^2}{\frac{(SE_1)^4}{n_1 - 1} + \frac{(SE_2)^4}{n_2 - 1}} \text{ where } SE_1 = \frac{s_1}{\sqrt{n_1}} \text{ and } SE_2 = \frac{s_2}{\sqrt{n_2}}$$

6.1.4 - Step 4: Find the p-value

The p-value depends on which alternative hypothesis is being used. It represents the probability or the area in the tail(s) of the distribution with the degrees of freedom described above.

$$P[t_{df} \leq t_{obs}] \text{ if } H_a : \mu_1 - \mu_2 < c$$

$$P[t_{df} \geq t_{obs}] \text{ if } H_a : \mu_1 - \mu_2 > c$$

$$2P[t_{df} \leq -|t_{obs}|] \quad = \quad 2P[t_{df} \geq |t_{obs}|] \text{ if } \quad H_a : \mu_1 - \mu_2 \neq c$$

6.1.5 - Step 5: State the conclusion:

Once the p-value is known, it has been compared to α, the significance level.

- If the p-value is $\leq \alpha$ the null hypothesis is rejected in favour of the alternative hypothesis.
- If the p-value is greater than α, the null hypothesis is true.

6.2 – Distribution Centre Validation

The validation process has been done after the verification. Overall the results reflected the reality, a part from some processes. The corrections on the distributions have been made in order to have a more accurate simulation. The following tables represent the final validated system after the modifications.

The validation has been made in particular on the creation modules in order to verify if the average of the recorded data from the simulation module reflect the data acquired observing the distribution centre.

6.2.1 –Validation of Customers

It has been observed that more than 100 customers enter in the distribution centre every day to collect their parcels. The observations have been made for 3 weeks, so the available data are the number of customers entering in the system for 3 replications, assumed that the distribution centre works for 5 days per week. The simulated system has been run for 10 replications (specifically for the validation and considering the buffer size) in order to obtain a precise analysis of the distributions inserted.

In the first attempt of validation for what concerns the customers entering the system through the customer service area, a substantial discrepancy was found between the number of entities obtained with Arena and the one collected in the Distribution Centre premises. With this information the complete model logic was revised and an important mistake was found: the distribution used at the first place in the Create Customers module was wrong (due to a writing error). After being replaced with the correct one the results were satisfactory and considered statistically valid.

Number of Replications/ Observation per Week	Customers by Replication	Customers Observed
1	600	546
2	542	574
3	609	588
4	533	
5	600	
6	611	
7	569	
8	574	
9	602	
10	544	

Table 2- Customers Arrivals

In order to apply the t-test on the data below, the excel function ‘’t-test: Two sample assuming unequal variance’’ has been used to obtain more accurate validations. In the table is shown the value of the t-Critical that has to be compared with the t-Stat.

If the test statistic is less than –(t-Critical) or greater than +(t-Critical), then the null hypothesis is rejected, otherwise the null hypothesis can be accepted and this means that the percentage of customers entering in the real system is not different from the percentage of those who come in, according to the simulated system.

Customers Arrivals	Simulated System	Real System
Mean	578.4	569.3333333
Variance	907.3777778	457.3333333
Observations	10	3
Hypothesized Mean Difference	0	
Df	5	
t Stat	0.581408984	
P(T<=t) one-tail	0.293094389	
t Critical one-tail	2.015048373	
P(T<=t) two-tail	0.586188778	
t Critical two-tail	2.570581836	

Table 3 - T-Test for Customers Arrivals

As shown in the table:

$$- (t\text{-Critical}) < t\text{-Stat} < + (t\text{-Critical})$$

$$-2.57 < 0.58 < 2.57$$

The null hypothesis is verified, so the outcomes of the simulated models reflect the reality.

6.2.2 - Validation of Parcels

It has been calculated that the number of parcels arriving each day is different during the week, but the total amount arriving each week is about 1000.

Number of Replications/ Observation per Week	Customers by Replication	Customers Observed
1	1570	1024
2	1451	1067
3	2657	1086
4	304	
5	110	
6	907	
7	1552	
8	2261	
9	81	
10	1276	

Table 4 - Parcels Arrivals

The same procedure of the customers has been used in order to validate if the number of parcels arriving in the distribution centre has at least a value similar to that registered by the simulated model.

Parcels	Simulated System	Real System
Mean	1216.9	1059
Variance	767135.6556	1009
Observations	10	3
Hypothesized Mean Difference	0	
df	9	
t Stat	0.568847814	
P(T<=t) one-tail	0.291686856	
t Critical one-tail	1.833112933	
P(T<=t) two-tail	0.583373712	
t Critical two-tail	2.262157163	

Table 5 - T-Test for Parcels Arrivals

The value of the t-Stat, compared to the t-Critical, shows that the results obtained from the virtual model are quiet similar to the reality since it has a value comprised in the critical interval.

$$-2.26 < 0.56 < +2.26$$

6.2.3 –Validation of Letters by Royal Mail

Royal Mail delivers letters using postal bags which can vary in weight with a maximum limit of 10 kg. When the data for this particular area were collected, it was impossible to count the precise

number of letters contained in each bag because of the lack of automated tracking systems or devices. Unfortunately, taking the bags and count their content precisely was unpractical due to the interferences that it would have caused to the normal execution of the service.

In order to have an estimate of the letters contained in the postal bags, their weights have been measured together with those of the average letter. Since the Distribution Centre specifically requires that the weight does not have to be over 7kg per bag, the quantity of mail has been assumed dividing the weight of the bag with the weight of the letter.

Weight of bags / Weight of a mail

The result was then multiplied by the number of bags received in the day in order to get the total amount of mail dealt with.

The Validation has confirmed that the data obtained with the simulated model present a marked difference with the reality.

This suggests that the assumption made were not precise enough to have a valid final output, as Table 6 and 7 show.

Number of Replications/ Observation per Week	Letters by Replication	Letters Observed
1	5957	9284
2	4467	7645
3	4137	9451
4	3378	
5	2712	
6	3214	
7	2400	
8	7299	
9	2952	
10	5478	

Table 6 - Letters by Royal Mail Arrivals

The t-test confirms the distance between the mean of the real system and the mean of the simulated one.

Letters by Royal Mail	Simulated System	Real System
Mean	8793.333333	4199.4
Variance	995974.3333	2562101.822
Observations	3	10
Hypothesized Mean Difference	0	
df	6	
t Stat	5.989927665	
P(T<=t) one-tail	0.000486537	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.000973074	
t Critical two-tail	2.446911851	

Table 7 - T-Test for Letters by Royal Mail

The value of the test statistic shows that the null hypothesis cannot be confirmed, it has been decided to correct the value of the distribution of this process since more accurate data are needed to simulate the real number of letters that are delivered by RM.

6.2.4 - Validation ofFlat Parcels by Royal Mail

While the flat parcels follow the same procedure of the letters delivered by Royal Mail, the means of the two systems are quite different. However, since the real data of this process are very different for each week, the percentage to have the same mean between the two systems is almost 90%.

Number of Replications/ Observation per Week	Flat Parcels by Replication	Flat Parcels Observed
1	1454	922
2	2232	915
3	247	2746
4	428	
5	247	
6	171	
7	528	
8	357	
9	654	
10	552	

Table 8 - Flat Parcels by Royal Mail

Although the same estimation as the letters has been used in order to calculate the quantity of flat parcels delivered, the t-Test presented in Table 9 shows that the data obtained in the model's output is close enough to the reality to be considered statistically valid.

Flat by Royal Mail	Simulated System	Real System
Mean	1527.666667	687
Variance	1113264.333	427705.1111
Observations	3	10
Hypothesized Mean Difference	0	
df	2	
t Stat	1.306765992	
P(T<=t) one-tail	0.160672386	
t Critical one-tail	2.91998558	
P(T<=t) two-tail	0.321344772	
t Critical two-tail	4.30265273	

Table 9 - T-Test for Flat Parcels by Royal Mail

6.2.5 - Validation parcels for DC by Royal Mail

The parcels intended to the distribution centre arriving each week are on average 100. Even if the number of parcels registered by the simulated system is a little bigger, the difference between the two averages is acceptable.

Number of Replications/ Observation per Week	Customers by Replication	Customers Observed
1	95	238
2	90	141
3	82	190
4	67	
5	116	
6	98	
7	155	
8	93	
9	106	
10	121	

Table 10 –Parcels for DC by Royal Mail

The statistic test, therefore, falls in the critical interval as shown in the table below.

Parcels for DC by Royal Mail	*Simulated System*	*Real System*
Mean	189.6666667	102.3
Variance	2352.333333	588.4555556
Observations	3	10
Hypothesized Mean Difference	0	
Df	2	
t Stat	3.00914518	
P(T<=t) one-tail	0.047483247	
t Critical one-tail	2.91998558	
P(T<=t) two-tail	0.094966495	
t Critical two-tail	4.30265273	

Table 11 - T-Test Parcels for DC by Royal Mail

7.1 - Count

Count	Average	Half Width	Minimum Average	Maximum Average
Record Customer	574.50	11.66	533.00	623.00
Record Delivered Mail in Engineering and Design Route	382.65	71.39	173.00	821.00
Record Delivered Mail in Halsbury Route	113.90	22.78	58.0000	268.00
Record Delivered Mail in Shops Route	258.45	48.60	134.00	550.00
Record Delivered Mail in Van Delivery Route	2771.15	503.79	1466.00	5937.00
Record International Mail Out	55.0500	12.50	24.0000	135.00
Record Mail Out	265.75	54.16	152.00	583.00
Record National Mail Out	210.70	42.19	127.00	448.00
Record Parcel for Staff	1263.65	219.98	475.00	2558.00
Record Parcel for Student	1616.40	281.27	678.00	3268.00
Record Parcels by Royal Mail for DC	118.35	12.25	60.0000	168.00
Record Parcels Picked up from Customers	565.95	16.34	490.00	623.00

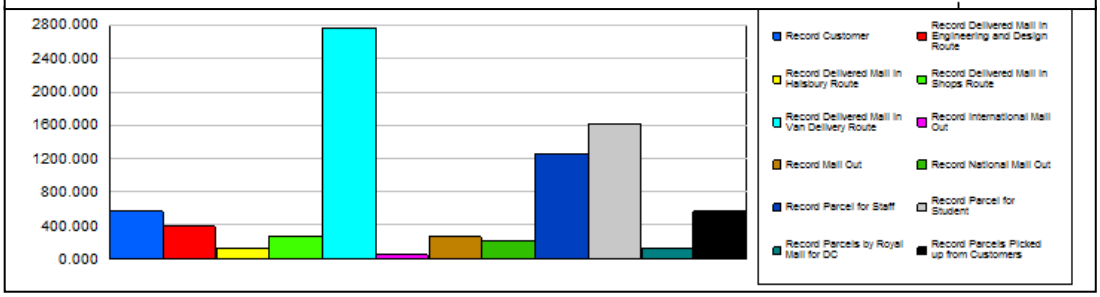


Figure 80 - Count Output Report

The screenshot above shows the average number of entities which enter or leave the system in a 5 days period. As can be seen from the graph the highest value of the figures is represented by the number of mail carried by the Van Delivery (2771), followed by the number of parcels addressed to students (1616) and staff (1263). By contrast, the lowest value recorded refers to the number of International Mail Out (210).

7.2 - Number Waiting and Waiting Time

As can be seen from the table below, concerning the *waiting time*(Figure 82), it is possible to observe that the highest value is represented by the Parcels storage process, with an average of 499 and a maximum of 1212 parcels (in the Number Waiting in Figure 81). In this context, this result could be explained taking into account that the storage of parcels is done by one employee, which is simultaneously involved in other processes.

Furthermore, the highest value shown in the "*number waiting"* is represented by the Queue in the *"Hold for Delivery Time 1".* This result can be easily explained considering the huge amount of mail

and flat parcels, waiting for the start of the Van Delivery round in order to be delivered to the numerous buildings around the campus.

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Batch Route 2 Letters.Queue	0.02784911	0.03	0.00023148	0.2756	0.00	95.0000
Batch Route 4 Letters.Queue	0.2356	0.19	0.00083333	1.3796	0.00	201.00
Batch Route 5 Letters.Queue	0.1688	0.10	0.00083333	0.5556	0.00	137.00
Batch Van Delivery Letters.Queue	1.9069	0.80	0.5223	7.9599	0.00	1558.00
Customer service.Queue	16.2447	0.53	14.0903	18.4745	0.00	136.00
First Sorting.Queue	77.8668	22.60	37.1179	246.36	0.00	1977.00
Hold For Delivery Time 1.Queue	279.62	47.13	144.75	513.42	0.00	1558.00
Hold For Delivery Time 2.Queue	4.8064	0.95	2.1797	9.9428	0.00	92.0000
Hold For Delivery Time 4.Queue	31.2877	5.56	14.5088	62.0137	0.00	196.00
Hold For Delivery Time 5.Queue	23.1406	4.33	10.2553	49.2924	0.00	166.00
Hold Mail for DHL Arrival.Queue	4.4199	1.01	2.0717	10.9234	0.00	44.0000
Hold Mail for Royal Mail Arrival.Queue	17.1702	3.29	10.6545	36.2808	0.00	166.00
Hold parcel Royal Mail.Queue	0.00107261	0.00	0.00000454	0.00460143	0.00	14.0000
Hold Resource Entity for Signal 2.Queue	0.1853	0.03	0.1670	0.3505	0.00	2.0000
Hold Resource Entity for Signal 3.Queue	0.1671	0.00	0.1670	0.1677	0.00	2.0000
Hold Resource Entity for Signal 4.Queue	0.1670	0.00	0.1670	0.1675	0.00	2.0000
Hold Resource Entity for Signal.Queue	0.0946	0.00	0.0935	0.0959	0.00	1.0000
International Mail Stamping.Queue	0.00604690	0.00	0.00069960	0.02977112	0.00	14.0000
Leave Distribution Centre for Route 1.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Leave Distribution Centre for Route 2.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Leave Distribution Centre for Route 4.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Leave Distribution Centre for Route 5.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Loading barrow 1.Queue	1.4947	0.43	0.4924	4.5205	0.00	72.0000
Loading barrow 2.Queue	8.4836	1.60	3.7205	17.9322	0.00	193.00
Loading barrow 3.Queue	5.9948	1.19	2.7673	13.4651	0.00	137.00
Loading Van Delivery.Queue	99.25	20.71	49.8828	250.11	0.00	1558.00
Mail Out Sorting National or International.Queue	0.0990	0.05	0.01462271	0.3714	0.00	54.0000
National Mail Stamping.Queue	0.02000241	0.01	0.00255637	0.1021	0.00	35.0000
Parcels Storage.Queue	499.09	124.09	85.2165	1211.95	0.00	2664.00

Figure 81 - Number Waiting Output Report

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Batch Route 2 Letters.Queue	0.02608278	0.03	0.00038052	0.2345	0.00	32.9692
Batch Route 4 Letters.Queue	0.08115696	0.07	0.00057803	0.5555	0.00	32.9690
Batch Route 5 Letters.Queue	0.07981433	0.05	0.00065789	0.3039	0.00	52.9853
Batch Van Delivery Letters.Queue	0.07208709	0.01	0.03731763	0.1609	0.00	0.3989
Customer service.Queue	3.3919	0.07	3.0379	3.6806	0.00	11.7888
First Sorting.Queue	1.8595	0.21	0.9909	2.7656	0.00	14.3840
Hold For Delivery Time 1.Queue	9.3491	0.38	7.7502	11.3153	0.00	22.9164
Hold For Delivery Time 2.Queue	3.8573	0.44	2.5099	6.4375	0.00	21.9024
Hold For Delivery Time 4.Queue	7.3170	0.25	6.1422	8.2035	0.00	21.9161
Hold For Delivery Time 5.Queue	7.9327	0.21	6.9487	8.7688	0.00	21.9113
Hold Mail for DHL Arrival.Queue	9.6918	0.52	7.7082	11.9539	0.00	21.8471
Hold Mail for Royal Mail Arrival.Queue	9.8780	0.33	8.4930	10.8810	0.00	21.8739
Hold parcel Royal Mail.Queue	0.00113267	0.00	0.00000474	0.00541344	0.00	0.04831440
Hold Resource Entity for Signal 2.Queue	11.1207	1.58	10.0183	21.0271	9.0181	33.0194
Hold Resource Entity for Signal 3.Queue	10.0261	0.00	10.0186	10.0614	9.0183	11.0460
Hold Resource Entity for Signal 4.Queue	10.0221	0.00	10.0176	10.0498	9.0175	11.0284
Hold Resource Entity for Signal.Queue	11.3533	0.03	11.2145	11.5068	11.2145	11.5068
International Mail Stamping.Queue	0.01219967	0.00	0.00233201	0.02646322	0.00	0.3901
Leave Distribution Centre for Route 1.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Leave Distribution Centre for Route 2.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Leave Distribution Centre for Route 4.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Leave Distribution Centre for Route 5.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Loading barrow 1.Queue	1.5255	0.20	0.9033	2.3157	0.00	11.0705
Loading barrow 2.Queue	2.6560	0.10	2.2342	3.0355	0.00	11.0448
Loading barrow 3.Queue	2.7658	0.11	2.4068	3.2605	0.00	11.0339
Loading Van Delivery.Queue	4.2675	0.14	4.0361	5.0553	0.00	12.5866
Mail Out Sorting National or International.Queue	0.04782561	0.02	0.00622243	0.1617	0.00	11.9414
National Mail Stamping.Queue	0.01078561	0.00	0.00247390	0.02967517	0.00	0.2012
Parcels Storage.Queue	40.0389	5.07	15.1854	52.7276	0.01668891	97.3598
Processing Royal Mail Parcel DC.Queue	4.3165	0.22	3.5599	5.2214	0.00	11.9772
Route 2 Process.Queue	0.4405	0.15	0.00	0.9177	0.00	1.7332
Route 4 Process.Queue	1.5012	0.16	0.9067	1.8392	0.2809	2.0509
Route 5 Process.Queue	0.7527	0.13	0.1474	1.2128	0.00	1.7117
Scanning parcels.Queue	2.0953	0.37	0.5102	3.3075	0.00	13.2734
Second Sorting.Queue	0.03371341	0.02	0.00374358	0.1211	0.00	11.9987
Storage of parcels.Queue	0.1168	0.04	0.03092510	0.3162	0.00	12.5296
Unloading Bag.Queue	2.8604	0.12	2.6066	3.6293	0.00	11.9040
Van Delivery Process.Queue	2.0783	0.10	1.4333	2.1500	1.4333	2.1500

Figure 82 - Waiting Time Output Report

7.3 - Utilization

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Amanda	0.1086	0.02	0.05441677	0.2093	0.00	1.0000
Andreas	0.05236306	0.01	0.03557303	0.1062	0.00	1.0000
Barcode scanner 1	0.0917	0.02	0.03686111	0.1883	0.00	1.0000
Barcode scanner 2	0.0917	0.02	0.03686111	0.1883	0.00	1.0000
Carl	0.07568422	0.00	0.06639392	0.0966	0.00	1.0000
Computer for Scanning 1	0.0917	0.02	0.03686111	0.1883	0.00	1.0000
Computer for Scanning 2	0.0917	0.02	0.03686111	0.1883	0.00	1.0000
Frank	0.1079	0.01	0.05877566	0.2043	0.00	1.0000
Igor	0.03643674	0.00	0.02679684	0.05915869	0.00	1.0000
Jack	0.1077	0.02	0.05430888	0.2104	0.00	1.0000
Kevin	0.05491405	0.01	0.03863986	0.1075	0.00	1.0000
Marc	0.02036213	0.00	0.01304539	0.02805986	0.00	1.0000
Michael	0.03573710	0.00	0.02580504	0.05736270	0.00	1.0000
Stamping Machine	0.00146904	0.00	0.00071378	0.00394884	0.00	0.5000
Tim	0.01977435	0.00	0.01327941	0.02821268	0.00	1.0000

Figure 83– Instantaneous Utilization

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Amanda	0.2895	0.04	0.1451	0.5582
Andreas	0.1396	0.02	0.0949	0.2831
Barcode scanner 1	0.0917	0.02	0.03686111	0.1883
Barcode scanner 2	0.0917	0.02	0.03686111	0.1883
Carl	0.2018	0.01	0.1771	0.2577
Computer for Scanning 1	0.0917	0.02	0.03686111	0.1883
Computer for Scanning 2	0.0917	0.02	0.03686111	0.1883
Frank	0.2878	0.04	0.1567	0.5449
Igor	0.0972	0.01	0.07145825	0.1578
Jack	0.2872	0.04	0.1448	0.5610
Kevin	0.1464	0.02	0.1030	0.2867
Marc	0.05429901	0.01	0.03478772	0.07482631
Michael	0.0953	0.01	0.06881343	0.1530
Stamping Machine	0.00146904	0.00	0.00071378	0.00394884
Tim	0.05273160	0.01	0.03541175	0.07523380

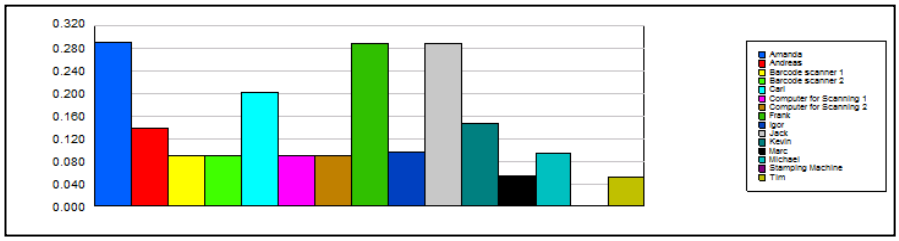


Figure 84 - Scheduled Utilization

There are two different kinds of utilization: instantaneous utilization is the fraction of busy resources to total available resources at any time; scheduled utilization is an overall measure of the total capacity on the total demand. In this case all the employees have the Instantaneous Utilization lower than the Scheduled one, this means that everyone can easily handle the overall load and that they are almost always busy during their working hours.

The lowest utilization is registered by the resources that, even if are involved in more than one process, they work in procedures that take few time to be fulfilled, for example sorting, stamping or delivery with barrows. This is the case of Marc, Tim, Michael and Igor whose utilization is more than half lower than other employees.

Frank is the resource that works more than the others maybe because he is the only one that deals with the storage of parcels and, even if the delay time of this distribution is calculated in seconds, the number of parcels to be stored is quite big to be handled by one single employee.

Overall the ideal utilization percentage of each employee should be at least 50%, but from the graph it is evident that the percentage of 5 human resources is less than 20% and 4 of them work less than 40%.

The utilizations for the computer for scanning, barcode scanning and stamping machine are almost the same because, a part from the periods of time in which they fail and they need to be fixed, they work for the whole day, so time is not an influent variable in the calculation.

7.4 - Total time

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Customer	3.4585	0.08	3.1050	3.7460	0.03709749	11.8645
Flat Parcel	18.1300	0.74	15.1820	21.8295	0.9180	36.9563
Mail	18.4521	0.24	17.7343	19.8829	0.9149	37.2338
Parcel	0.00	0.00	0.00	0.00	0.00	0.00
Parcel for Staff	20.9203	0.61	18.1612	24.0268	0.5367	54.1014
Parcel for Student	41.5471	4.36	20.3582	53.6472	0.1154	98.1135

Figure 85 - Total Time Output Report

In the table is shown that customers are served in a fast way since their average time spent in the system is 3 minutes. This process is quite efficient since the first idle member of the staff provide assistance whenever a customer arrives. This has been specified with the use of a set in which are included all the members.

Parcels for Staff spend less time in the distribution centre than the parcels for students since are delivered to their destination soon in the morning; the parcels for students are stored and they may wait in the centre more than one day if a customers doesn’t come to pick them up.

IMPROVEMENTS

8.1 - Suggested Changes to Reduce the Number of Parcels into the Storage due to Storage Capacity Limitations

According to the maximum capacity of the actual storage, the number of stored parcels for students exceeds the allowed capacity of the parcel's area; it causes layout drawbacks reducing the space available to conduct the daily processes. This problem is due to the fact that, in some circumstances, customers postpone the collection of their own parcels causing an unexpected permanence of them in the system.

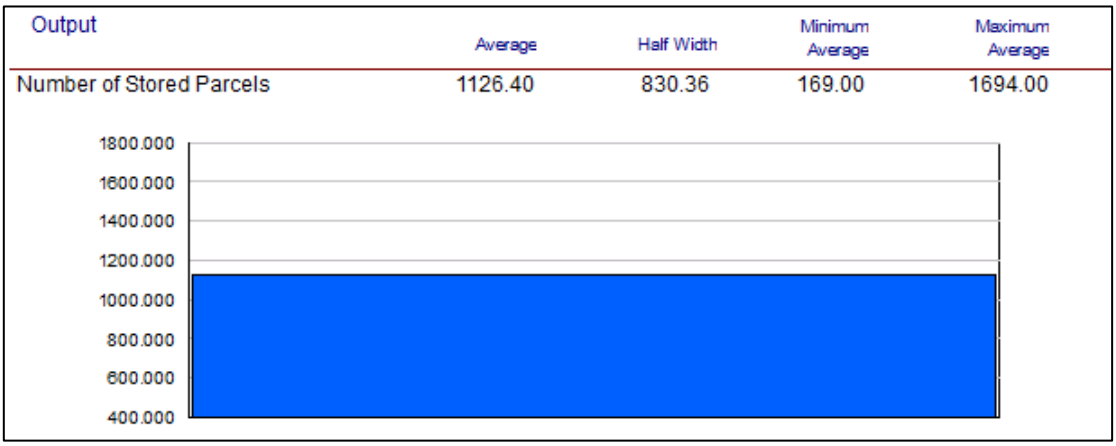


Figure 86 - Number of Stored Parcels Statistic

As the graph shows, it is clear that (looking at the average) the number of stored parcels can easily exceed the maximum capacity allowed by the Distribution Centre (750). The analysed values and the maximum capacity declared by the team manager of the Distribution Centre are based on the assumption that the size of each parcel has the following characteristics:

Format	Examples		Max length	Max width	Max depth
 **Standard Parcel**	Gifts, shoes, heavy or bulky items	Ladies boots, portable speakers, winter puffa coat, desk lamp	61cm	46cm	46cm

Figure 87 - Standard Parcel Weight

The exceeded amount of parcels causes layout causes inefficiency, dissatisfaction and stress of the staff as well as an increase in the processing time of the storage. The problem related to the capacity of the storage area could be overcome in two different ways. The first one is linked to a different approach with the customers and the other way concerns the optimisation of the layout with the utilisation of neglected space.

8.2 - Adoption of New Incentive Policies for Changes inCustomers' Behaviour.

The adoption of new incentive policies has been suggested in order to encourage customers to not postpone the collection of their parcels. One example could be fix a limited period of time to withdraw parcels in order to assure that the capacity of the storage will not be reached quickly. The actual communication system of the Distribution System is based on an automatic notice sent by mail to the customer. However, there is no charge if the customer does not turn up to withdraw its staff. This has been considered as the main reason of the accumulation of parcels in the storage. Furthermore, this solution is strictly related to the commitment of the customers and their reliability.

In order to demonstrate the relation between customers' behaviour and storage capacity, it has been considered the adoption of a policy by which the customer will be forced to withdraw its parcel within three working days from the moment of notification: after that he will be charged of a certain amount of money. On this basis, a new scenario has been reproduced in order to improve the system. The new customers' schedule has been defined and forecasted thanks to the assumption made and after interviews and comparisons with the manager of the Distribution Centre.

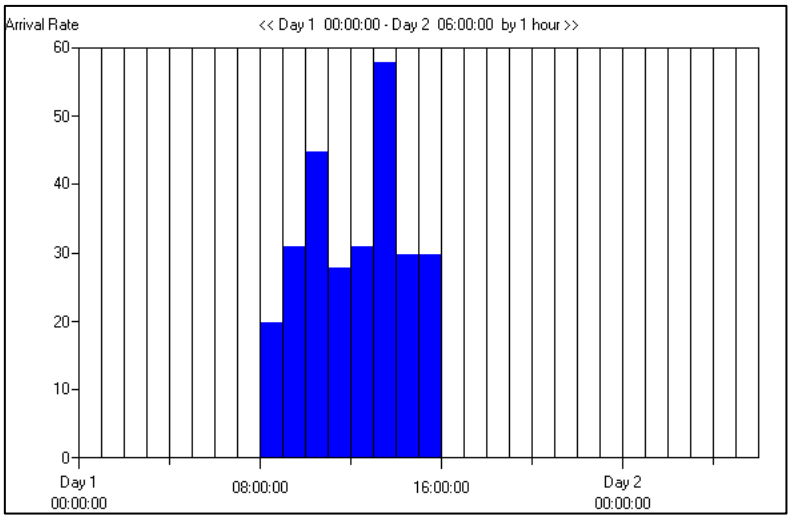


Figure 88 - Customers Creation Schedule (Predicted)

As it can be seen from the graph below there has been a significant reduction of 47% in the average amount of not collected parcels after the adoption of a new policies listed above. Considering that the maximum capacity has been fixed at 750 parcels, the maximum average is still higher than the limit. However, this improvement could represent a significant way to solve or mitigate the problem related to the capacity of the storage and its consequences on the quality of the work reducing the stress of the resources caused by an overload of stored parcels.

Figure 89 - New Number of Stored Parcels

The suggested improvement mentioned before could be implemented into the real system whit adding cost. As a matter of fact, the customer could be informed of the new policies using the actual automatic communication system by which the server send an automatic email to the customer informing of the new policy.

8.3 - Adoption of a New Layout to Increase the Maximum Capacity of the Storage Area.

The observations that have been performed on site demonstrate how the space, in volumetric terms, is not used in an efficient way. In fact, the area in which the parcels are catalogued, pending to be picked up by customers, uses only part of the height available. Simple improvements, such as adding additional shelving in the upper part should be carry out. Furthermore, the detachment of the shelving from the wall would allow access from both sides by increasing the volumetric capacity.

The reasons for which these measures have not previously been made are to be found in the fact that this area is a vital source of daily processes of the Distribution Centre. Therefore, these changes should be carried out on holidays and would require at least six days to perform these changes including the training staff for the disposition.

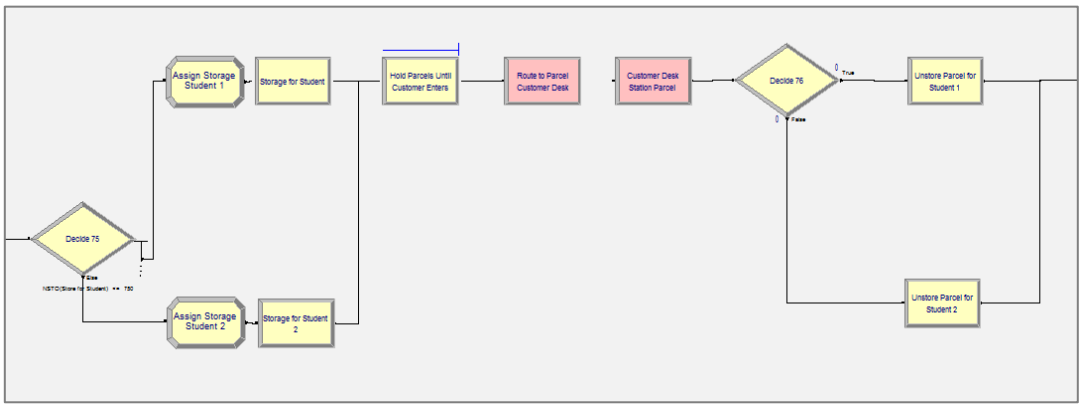


Figure 90 - Added Storage (Representing the New Four Shelving)

In the following simulation, considerations and suggestions made before (regarding the new policies adopted with customers) will not take into consideration in order to highlight the improvements due exclusively to the change of the layout disposition.

As the figure above shows, in order to simulate the disposition of four new shelving in the layout, a new storage for student has been introduced. In this way both the storages will be able to not exceed the new capacity. It will be fixed at around 1500 parcels, allowing the Distribution Centre to better manage the inequality between the Customer collection and the Parcels delivering.

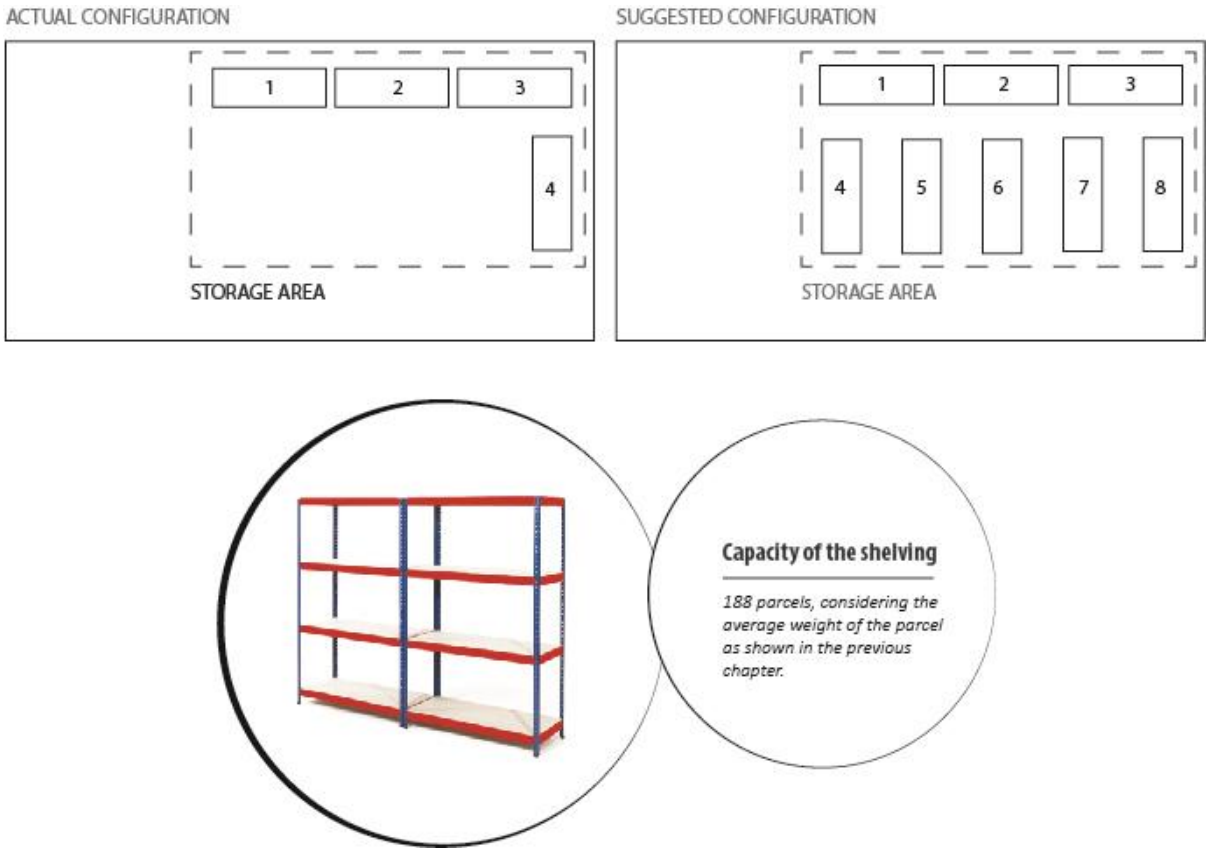


Figure 91 - Suggested Layout Configuration

The new layout involves the introduction of four new shelving, thus able to double the capacity of the area. The working conditions of the employees will not suffer the consequences being the distance between the various shelves suitable to the passage and to their use.

Output	Average	Half Width	Minimum Average	Maximum Average
Number of actual stored parcels Storage 1	622.40	315.90	169.00	751.00
Number of actual stored parcels Storage 2	504.00	586.31	0.00	943.00

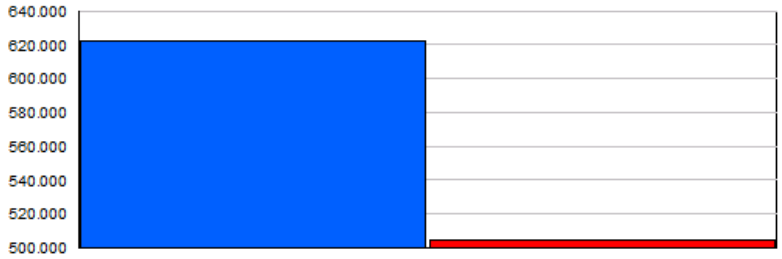


Figure 92 - Number of Parcels with the Introduction of New Storage

Clearly the implementation of a new policy for clients and expansion of the restricted area of the parcels would further reduce the number of parcels in stock within the Distribution Centre. For this occasion we strictly recommended to adopt with higher priority a change in the actual policy because it represents a quick and without cost improvement. On the other hand a new layout needs a stop in the production and funding to buy new shelving. The last one expenditure has been calculated using the current price on the market of industrial shelving and it is around £528.

8.4 - Improving Resources' Utilization

8.4.1 - Original Model

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Amanda	0.2942	0.13	0.1451	0.3741
Andreas	0.1334	0.03	0.1012	0.1732
Barcode scanner 1	0.0964	0.05	0.03686111	0.1286
Barcode scanner 2	0.0964	0.05	0.03686111	0.1286
Carl	0.2073	0.02	0.1935	0.2371
Computer for Scanning 1	0.0964	0.05	0.03686111	0.1286
Computer for Scanning 2	0.0964	0.05	0.03686111	0.1286
Frank	0.2824	0.10	0.1567	0.3447
Igor	0.0937	0.02	0.07709689	0.1156
Jack	0.2921	0.12	0.1448	0.3703
Kevin	0.1379	0.03	0.1062	0.1607
Marc	0.04752347	0.00	0.04555621	0.05092545
Michael	0.0917	0.02	0.07520952	0.1183
Stamping Machine	0.00162859	0.00	0.00087804	0.00255022
Tim	0.04495760	0.01	0.03541175	0.04881578

Figure 93 - Original Model Scheduled Utilization

As can be seen from the results obtained from the original model, the average scheduled utilization of each employee does not exceed the 30%. This statement could be easily explained taking into account that the number of employees engaged in the Distribution Centre, far

outweighs the number of processes carried out by the same. In addition, it is important to highlight that because of the scheduled deliveries, the working time of the workforce is quite fast and fluctuating: in other words, only few hours per day is required the maximum effort of all the team, considering that the Distribution Centre is dependent on other timetable couriers' delivery.

However, after analysing the outcomes, the suggested improvement has involved the number of employees involved in the parcels' area for the storage (considering that this process requires more time due to the huge amount of parcels which come into the system and for this reason would be preferable to exploit more resources). More specifically, in the real model has been observed only one employee in charge for the storage of parcels and this could represent a limitation of the system. In this context, in order to increase the lowest employees' utilization, it has been assumed useful to spread the storage process among those employees (Igor, Marc and Michael).

8.4.2 - Improved Model

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Amanda	0.3074	0.12	0.1689	0.3805
Andreas	0.1458	0.04	0.1078	0.1804
Barcode scanner 1	0.0964	0.05	0.04239120	0.1242
Barcode scanner 2	0.0964	0.05	0.04239120	0.1242
Carl	0.2118	0.02	0.1908	0.2406
Computer for Scanning 1	0.0964	0.05	0.04239120	0.1242
Computer for Scanning 2	0.0964	0.05	0.04239120	0.1242
Frank	0.3111	0.11	0.1900	0.4078
Igor	0.3419	0.11	0.2071	0.4267
Jack	0.3035	0.12	0.1611	0.3793
Kevin	0.1508	0.04	0.1168	0.1918
Marc	0.3095	0.11	0.1893	0.4044
Michael	0.3444	0.11	0.2071	0.4300
Stamping Machine	0.00171806	0.00	0.00084903	0.00300449
Tim	0.05955072	0.01	0.04705465	0.06614706

Figure 94 - Scheduled Utilization

After the changes made, it can be noticed that the overall employees' utilization has considerably increased. As a result, it is also clear that in the new model there has been an attempt to balance the resources' utilization, avoiding imbalance. However, as can be predicted, the only utilization that has slightly decreased is related to the employee (Frank) who in the original model was the only responsible of the storage of parcels.

8.5 - Improving Costs of Employees Using Part-Time Contracts

In this improvement, the focus has been placed to the cost of the employees and if it can be significantly reduced without affecting the core system processes.

In order to achieve that, the 3 employees that have the lowest utilization have been considered for a change in contract: Full-time to Part-time. Therefore, their working time schedule has been changed as Figure 96 shows.

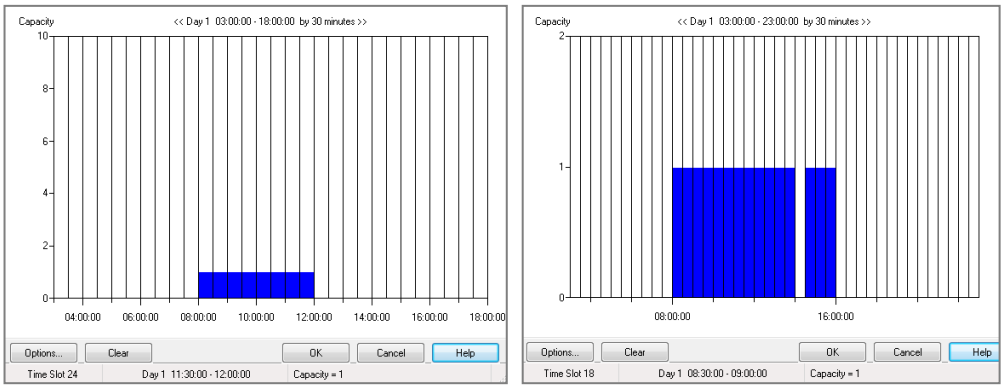


Figure 95 - Part-time Schedule (Left) and Full-time Schedule (Right)

The part-time shifts starches only in anti-meridian hours from 8 to 12 for a cumulative working time of 4 hours per day.

The changes have been analysed through the stand-alone software Process Analyser doing a comparison between the Case Base Scenario and the improved new system: the responses considered are the one concerning the main services provided by the Distribution Centre (Figure 97).

	Scenario Properties				Responses				
	S	Name	Program File	Reps	All Resources.TotalCost	First Sorting.Queue.WaitingTime	Second Sorting.WaitTimePerEntity	International Mail Stamping.Queue.WaitingTime	Scanning parcels.Queue.WaitingTime
1		Case Base	4 : Case Base.p	20	3858.223	1.860	0.034	0.012	2.095
2		Scenario 4	1 : Scenario 4 P	20	3221.030	1.888	0.196	0.008	2.101

Figure 96 - Scenarios Core Processes Comparisons

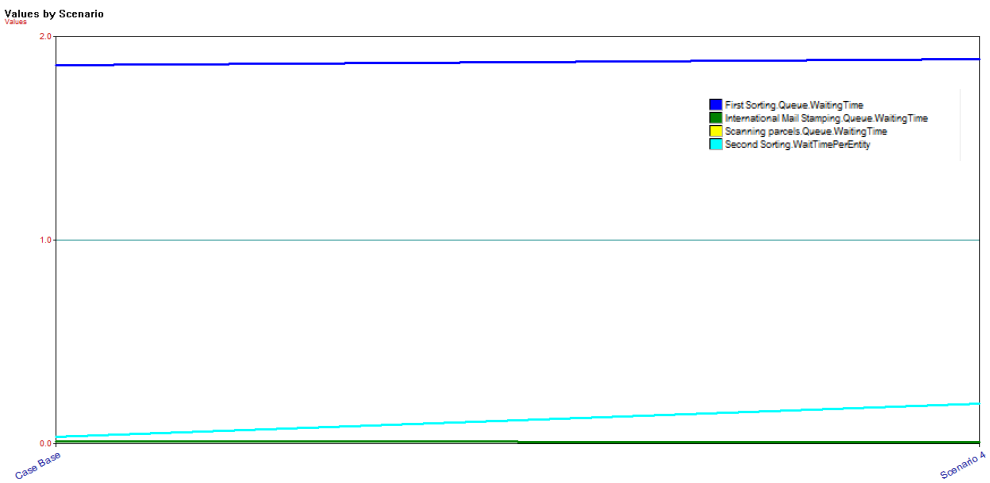


Figure 97 - PAN Analysis

As it can be seen from Figure 97, core responses have not substantially changed although less resources are present in the second half of the working days.

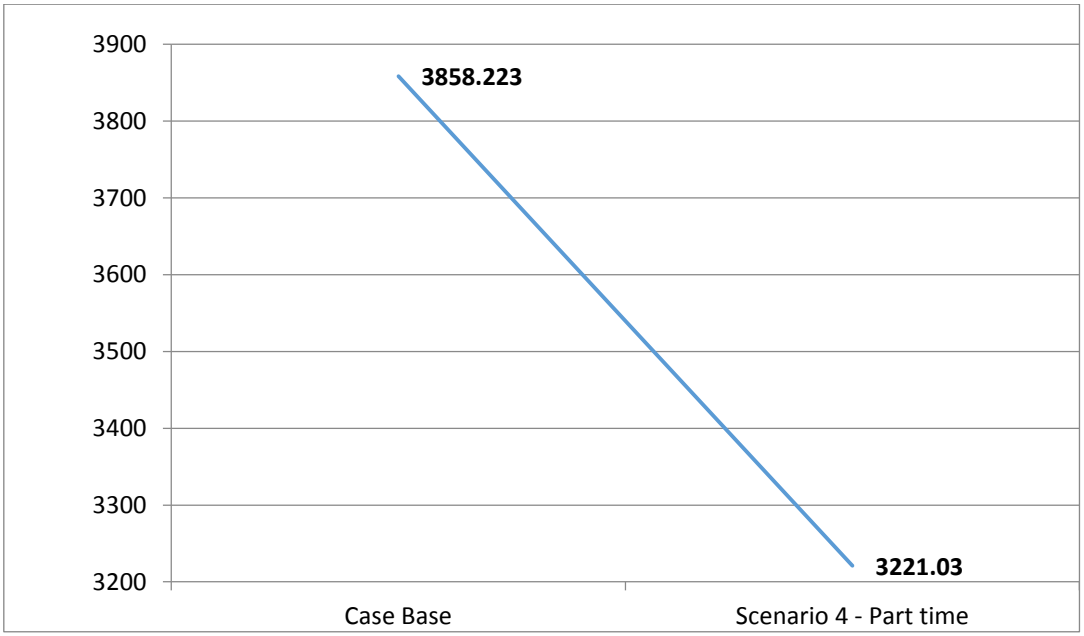


Figure 98 - Base Case and Improve Scenario Costs' Comparison

On the other hand, the cost due to the payment of the employees (which is relative to an amount of days equal to 5), has significantly decreased from £3,858.22 to £3,221.03 (Figure 98). If the monthly cost is analysed (5 days multiplied by 6) it can be noticed how the reduction of cost can be a valid scenario whenever some financial cuts are needed:

$$Monthly\ Case\ Base = £3{,}858.22 * 6 = £23{,}149.32$$
$$Monthly\ Improved\ Scenario = £3.221.03 * 6 = 19{,}326.18$$

After an accurate observation and evaluation of the outcomes obtained through the simulation of the Brunel's Distribution Centre it has been concluded that the performance and efficiency of the centre is overall satisfied, apart from two interconnected problems.

The first inefficiency has been found in the storage area where the delivered parcels have to be stored; it has been noticed that the number of accumulated parcels far outweighs the number of customers arrivals during one replication (5 working days), causing an overload of the available shelving and a consequent reduction of space. An addition of four more shelving, with a capacity of 188 parcels each, would result in a more efficient and effective management of the stored parcels; moreover, the Distribution Centre should also calculate the possibility of improving the communication system with customers, adopting a more severe policy for the collection of parcels in order to stimulate students to gather their staff as soon as possible. These two improvements would soon prove a positive choice because despite extra costs, the number of parcels that could be stored will increase while the number waiting will reduce.

Another drawback has been confirmed examining the outcomes regarding the resources' utilization. The data obtained thorough Arena have shown an underutilization of the majority of the employees, issue already discussed with the manager of the centre. The main cause of this inefficiency lies in the number of processes involved and their low execution time. The suggested improvement is to allocate a higher number of workers in the process that has the longest queue and work-in-process time: the storage area. In this way, combining the improvement related to the enlargement of the storage with the latter suggested, it is possible to guarantee a balanced workforce and a better management of the enhanced space.

In addition, if the analyst would have been required to conduct an analysis based on the costing of resources supporting a change in management strategies, it has been found that having 4 Full-time employees and 3 Part-time ones could reduce the money outcomes of the Centre without affecting the overall efficiency of the processes involved.

After having conducted a simulation of the real system from its early stages of field research and data collection to the final refinements and improvements, it has been acknowledged how much work and effort is needed in order to produce reliable outcomes from the modelled system in Arena. Thinking outside the box and be able to visualize problems and their solutions with a different perspective sharing a team's vision, has been found vital in order to execute valid modelling and simulation's techniques over a fair share of work.

In conclusion, it can be stated that overall the Distribution Centre has a well organised delivery system followed by an efficient management of the processes however some improvements and investments have been found with the creation of what-if scenarios and the analysis of their relative reports.