

A Newly Designed Baggage Transfer System Implemented Using Event-Based Simulations

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Abstract This paper proposes a newly designed system for baggage transfer, which utilises the Nexus Metro system in Newcastle-Upon-Tyne by running a pendulum freight train system between the Haymarket and Newcastle Airport to carry travellers' baggage. This system is capable of serving all passengers departing from Newcastle Airport in a day, with a capacity of 9750 bags across 26 freight train journeys. Following the initial solution two more solutions were designed with the aim of maximising the utilisation of the metro tracks by saturating the system with freight trains on a 24-h system. All solutions have been replicated using models designed and validated by event-based simulation using SIMUL8, a simulation modelling software package.

Keywords Systems design · Baggage transfer · Simulations

1 Introduction

1.1 Motivation

With a number of travellers using cars possibly due to baggage transportation complications, a new system could

encourage more users of sustainable transport, possibly providing environmental benefits. In the absence of baggage on passenger rail, the current passenger users could benefit from a more comfortable baggage-less journey. People may therefore benefit from a social point of view, it is also more likely that people will travel if the journeys can be embarked upon with fewer complications and more comfort. It would appear that there is a need for a new system which can improve the utilisation of sustainable transport such as rail and facilitate the passenger.

1.2 Objectives

The objective of this study is to propose a new baggage transfer system to facilitate the passenger in travelling with baggage and improve utilisation of sustainable transport.

1.3 Methodology

Case studies of current baggage transfer systems are evaluated to identify strengths and weaknesses. These can be investigated through online research. Following the case studies, work is started to design a new system incorporating this newfound knowledge as well as using innovative ideas to further benefit the system.

A proposed design is evaluated using simulation-based software, in the form of SIMUL8. The utilisations of the tracks on this design are analysed. Following this, two more designs are created which focused on saturating the system with freight trains in an attempt to maximise the track utilisations.

All of the designs proposed focus on a pendulum system between a collection hub at Haymarket and Newcastle Airport. Finally, an alternative design to a currently non-functional system which should facilitate the passenger to

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the degree whereby sustainable transport will become a more viable option is designed and evaluated.

1.4 Contribution to Knowledge

This system design study contributes to the development of a new concept for handling passenger's baggage. Specifically it proposes a new way of transporting heavy bags by introducing a new system for baggage transfer between a city centre and an airport. It is one of the very first studies to propose that check-in of a heavy bag can occur in a city centre and then transported to an airport separately from the passenger who owns it. This is to eliminate the hassle of carrying heavy bags when we travel.

For the new designs, collection of information about policies and practices of freight forwarding companies was needed. Therefore, a market research was undertaken to understand if such a system has potential for market uptake. The design work required the identification of technical parameters of the new system followed by evaluations of its performance using simulation modelling.

2 State of Practice

2.1 Company Policies

Before beginning the process of designing concepts, it was important to analyse current systems in use. In the case of designing a baggage transfer system, these cases would be companies that transfer luggage on a domestic level. Three companies were looked at as having examples of a system that transports baggage across Europe: DHL, FedEx and SendMyBag.

Company websites were studied to confirm that the companies were functional in the field of non-passenger transport. The company websites were limiting in the technical details they would provide about the system. This led to the second step of the case studies: contacting the companies directly to ask questions about their systems.

The information that was asked of the companies was the following:

- The mode of transport that is used to transfer the baggage, i.e. car, plane or train.
- Length of time the baggage spends in storage.
- What form the bags are transported in, i.e. crates, loose or plastic film.
- The time patterns of the transfer of the baggage, do the bags travel overnight, during daytime or both.
- The method of tracking that is used for the baggage.
- The amount of automation involved in the process.

- The amount of times baggage is separated and reconsolidated.
- The standards that are followed by the company with regards to baggage transfer.

This work did not lead to any gain in knowledge of current systems as none of the companies provided a response with answers.

2.2 European Baggage Transfer

It was decided that a cost analysis of delivery services may be of useful information. Five companies were analysed using their online tariff lists to understand the cost of sending different mass bags across different distances. The companies were: DHL, ParcelForce, DPD, FedEx and Yodel. Graphs were plotted to identify the trends in their pricing.

The masses of bag used in the study were 5–30 kg in intervals of 5 kg to represent the mass of bags most likely to be transported by a person. Five different locations were chosen to deliver to from the UK. These locations were selected based on being in different tariff zones for DPD. These locations were: France, Austria, Italy, Finland and Greece [1].

Figure 1 shows the impact that the mass of a bag and distance to travel has on the price of a delivery using DPD.

This is an example of service charges being as expected, where the cost of the delivery increases linearly with the mass of the bag as well as increases with the increase in distance.

Some companies such as Yodel would contrast to this with a pricing structure that would fluctuate inexplicably, Fig. 2. This suggests there could be complicated variables that will influence the costs of transferring baggage. Therefore, clearly it may not always be the more straightforward linear costing as shown in Fig. 1.

A graph, Fig. 3, was also made to find the cost that companies would charge to deliver bags of different masses across the UK. In this case, the same distance was used each time and only the bag mass was changed.

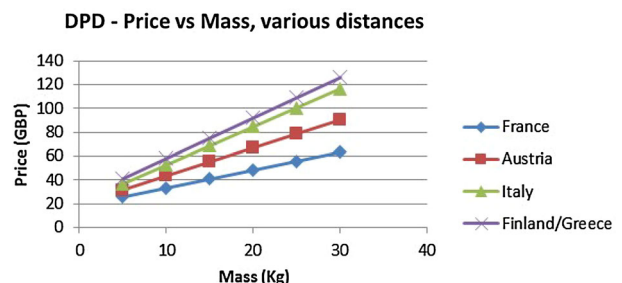


Fig. 1 DPD, price versus mass chart, data from DPD [1]

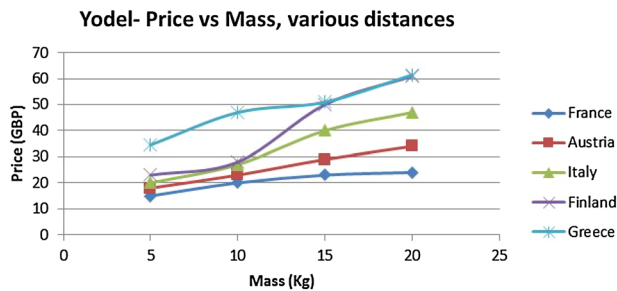


Fig. 2 Yodel, price versus mass chart, data from Yodel [13]

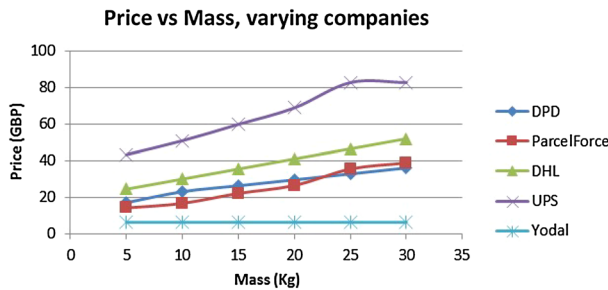


Fig. 3 All companies price versus mass chart, data from UPS [14], DPD [1], Yodel [13], Parcel Force [15] and DHL [16]

Most of the companies have a similar pricing system where the price increases as the bag mass does. Yodel, however, oddly does not change the cost of the delivery at all for any bag mass changes, this was even confirmed by Yodel staff using the online Q&A service.

This is evidence that there are relatively no more charges incurred in transporting heavier bags using land-based transport. This is contradictory to the understanding that the heavier bags would cause an increase in fuel consumption. It is possible that the price for this increase in fuel consumption is negligible in comparison to all the other costs induced.

2.3 Travelling by Car

A number of travellers use a car to travel as handling personal baggage is too impractical using other methods. This is clearly not an ideal solution to the problem as vehicles are not only an inconvenience to transport long distance, due to possibly needing to pay expensive tolls on roads, ferry costs and inevitably incurring large petrol costs.

In a world working towards a more sustainable future, where the accumulations of greenhouse gases are not such a cause for concern, it would be ideal for travellers to use public transport and not rely completely on personal vehicles to travel. There are also many who cannot afford the luxury of their own automobile and this option is therefore completely unavailable to them.

2.4 Luggage in Advance

Similar to the options that were available in 1960, ‘Passengers luggage in advance’ explained by Peter Kenyon, there are current systems that will deliver a suitcase to a different country for a small fee. Companies like ‘sendmybag.com’ have stated that they use courier services such as UPS to provide such services. One flaw in using this service is that there are usually tight restrictions on the times for bags to be picked up from the customer. This can make the service unusable in cases where a person cannot be at home during the pickup times, a very real problem for those who work 9–5, the same time window where the bags would need to be picked up.

2.5 Public Transport

This is probably the most common method after using a car. This system is the most sustainable, however, many are discouraged from this service due to the need to handle their bag the entire duration of the journey. Some have been quoted saying, “I once travelled with a bag and I was so paranoid the whole journey, I wanted to get off at every stop and check it was still there”. [2]. How are people expected to want to use public transport with fears such as this? There are also more practical problems such as people not being physically able to handle heavy bags on services where they are required to load and unload the bag themselves.

After looking at all the available options it appears that baggage still creates a problem for those travelling. A new design for a system which can resolve this problem by handling the baggage that people travel with would therefore be highly desirable.

2.6 CAT: City Airport Train Vienna

The City Airport Train connects the Vienna city centre with the airport in 16 min every one and a half hours and is a good example of baggage handling system in operation. The system is operated parallel to commuter trains and Inter-City-trains. The big benefit of the CAT service with the others is that passengers are able to check-in and drop off their baggage at the Vienna City Air Terminal directly in the city centre up to 75 min before take-off. The procedure is the same as at the airport. The baggage must be delivered at drop counters like at the airport and will be transported on a conveyor belt to a storage room. There it will be loaded on a trolley which is delivered to a separate and securely locked storage compartment in the train. At the Vienna Airport the trolley will be unloaded from the CAT-train and the baggage will be put on a conveyor belt

which brings in the baggage into the airport baggage system.

From the moment the customer delivers the baggage to the CAT-counter, the baggage is separated from the passengers, also when loading and unloading the train, so the total system meets the requirements of the air transport legacy.

Every person with a valid ticket is allowed to use the train, tickets are also available in the train. But only people who have a CAT-ticket are allowed to use the check in and baggage drop off. Additionally only passengers who take airlines which are in co-operation with CAT can use the baggage drop off. Currently, 20 carriers have got a contract with CAT so their passengers can check in at Vienna City Air Terminal.

CAT also had the idea of transporting baggage the other way around and to check it through from the plane into the train. The Vienna City Air Terminal also has a separate IATA-code but two reasons preclude this idea till now. Firstly, at the Vienna City Air Terminal an additional customs office must be installed and secondly, it is very difficult to guarantee that the baggage is in the same train as the passenger. If the situation happens that the passenger reaches the train but the baggage misses it the passenger has to wait half an hour at the City Air Terminal for the next train delivering the baggage.

3 Literature Review and State of the Art

Simulation modelling allows proposed designs to be analysed; they can be validated and verify hand calculations. Operating efficiencies can be measured and utilisations maximised. In this particular design, simulation modelling allows the utilisation of each section of the track to be analysed individually.

Simulation modelling has already been used effectively to model different scenarios such as rail yards [3], freight implementations to a passenger rail [4] and also complete rail networks. Specifically simulation modelling has been used to explore aspects of the metro system [20], utilisations have been measured for stations and railway tracks and transit times recorded for trains to move between stations and their time stationary at each station. The work discussed in this paper builds on this work where utilisations of railway sections are analysed similarly using simulation modelling software [4].

There is software designed with the focus on simulating the detailed movement of rail vehicles, such as Villon. This software allows details such as exact infrastructure modelling to be modelled. There is also an increased amount of flexibility and detail in the operation modelling of a network using Villon.

Easier to use and more broad ranged, softwares such as ‘SIMUL8’ and ‘Arena’ have also be used for less complex modelling of rails. Some have used non-specific software to model tracks and achieve optimal track layouts. Simulation modelling software which utilised SLAM II language for their analyses’ was used. Using analytical models to study delays, capacity of tracks between Downtown Los Angeles, Long Beach and Los Angeles ports was decided against compound delays and ripple effects at areas such as complex junctions causing problems [5].

Simulation modelling can be more favourable than analytical modelling as real life systems can be of great complexity, which is an area where analytical modelling may struggle to achieve clear analysis. Simulation modelling however is able to consistently achieve these accurate results.

After looking at the work of others using simulation modelling, it was a clear choice to model the system using such a software; SIMUL8 in this case. Schedules of passenger and freight trains were implemented to the system and adjusted with ease. SIMUL8 also allowed evaluation of the line between Haymarket and the airport to not only ensure that each design was validated but also allow their track utilisations to be compared to one another.

4 Technical Considerations of Design

4.1 Containerisation

Different containerisation options for baggage to be transported via aircraft have been investigated [6]. There are points of interest relevant to designing a system. The paper illustrates the importance in sorting the baggage as soon as possible and small a number as possible, i.e. it would be better to sort 10 sets of 5 bags than one set of 50. The reason for this is that there is an increased probability that baggage will be lost due to errors and delays when sorted in a larger quantity. The paper concludes that decentralising the sorting method reduces handling costs and transfer times. Though this is mainly applicable to the sorting of containers for airplanes it can be considered relevant to railway vehicles too.

4.2 Multi-modal Transport

Advantages and disadvantages of combining modes of transport for freight transfer have been investigated, with railway and road vehicle being one of these more relevant cases [7]. Figures 4 and 5 show a comparison of trucks versus combined transport and the position of optimal multi-modal transport point. Advantages of road transport are raised. Trucks are more flexible and can reach almost

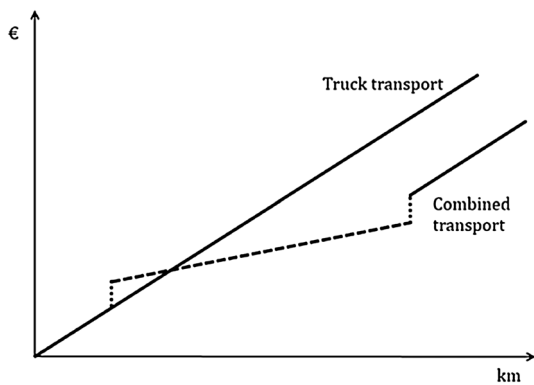


Fig. 4 Trucks versus combined (Reis et al. 7, pp 22)

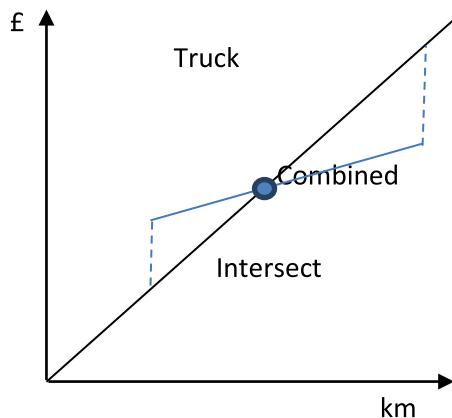


Fig. 5 Optimal multi-modal transport point

any point, not limited to stops along a single line. They are compatible to travel through any country, as all countries contain roads, most of which are passable by truck. There is also no faster way to deliver goods for short to medium distances. Finally, delivery by road incurs the least costs as there are only fixed costs for truck such as maintenance and fuel consumption costs. There are however problems associated with delivery by vehicle such as the fact that this method does not run on a tight schedule as a railway solution does. Road vehicles are also large contributors of CO₂ emissions and are becoming increasingly undesirable within society due to this. The costs of running a vehicle on the road are constantly increasing and will continue to increase with the exhaustion of fossil fuels; this makes road-based transport a temporary solution and not so viable for the future.

After a certain distance, it becomes more suitable to use combined transport as a solution to baggage transfer.

To move this intersection point towards the left on, making combined transport cheaper for shorter distances, a couple of changes can be made. Reducing the distance between baggage hubs and the train stations reduces the pre-carriage travel costs. There can also be improvements

made to the transfer units used on both train and road vehicle, making the crossover of cargo between the two more simple and efficient.

Figure 6 illustrates just how much more CO₂ emissions are contributed by road than other transport methods. This will of course become outdated very fast by the injection of electric and hybrid vehicles into society.

As this project is based on the transfer of baggage between two fixed points with a readily available metro line it would be most suitable to use railway only and not use two modes of transport together, which would complicate the system and scheduling.

4.3 The Client

The average age of a leisure traveller is 47.5 years old and the average age of a business traveller is 45.6 years old [8].

More importantly in 2012, 33 % of domestic business flights included air travel as opposed to just 11 % of leisure trips. 79 % of leisure trips used a car compared to the 48 % of business trips which used a car. These facts further demonstrate that cars are the regular choice of leisure travellers, most likely due to the handling of their baggage.

Though the information here is focused on travellers within the US, where there is obviously a different infrastructure to that of Europe, it is still a fair indicator of the target audience of the system design.

The passengers who the system is set to facilitate are those who wish to travel without needing to have a baggage constantly on their person. In the case of leisurely travellers this could be most effective as leisurely travellers can have the tendency to buy many goods such as souvenirs whilst on holiday without thinking about the logistics of their newly prized possessions. The system will allow them to send additional bags back home with time constraints of their selection. Many leisure travellers will also stay in hotels whilst abroad, this can cause concerns for those who have a flight home late in the day but are required to check

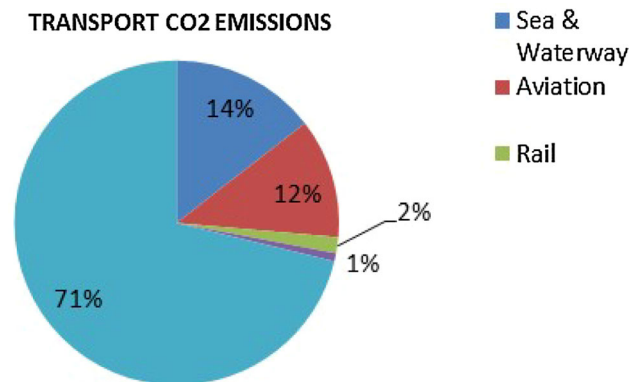


Fig. 6 CO₂ emissions [7]

out of their hotel earlier in the morning. The system will prevent this large group of people from being stuck with their bags for the duration between these times. Instead these travellers can drop their bags off and be free of the constant worry attached to the baggage.

There are also those who travel for business trips, these can often be people who will have a flight booked at a very short notice and will require a bag to be packed up and sent ahead of them to a destination. It is common for these trips to go to heavily populated areas such as busy cities where the use of cars are highly problematic, causing the handling of baggage to result in limitations of freedom when they arrive at their destination.

The final group of users would be those who have too much baggage to travel with at once. For example students relocating to university may wish to take their many bags to a hub over the course of a week or so for a later flight. This is a facility which is currently not so readily available.

5 Physical Design Elements

There are a number of physical aspects of the baggage transfer system which have been looked at. The real world system from the customer dropping a bag off at the collection hub to bags being unloaded from containers at the airport has been designed.

5.1 Baggage Traffic

The physical elements of the design are based on the volume of traffic that flows through the system. This volume of traffic is estimated based on a variety of assumptions.

To estimate the number of travellers from Newcastle Airport, timetables for departures were looked at. The timetable on Monday the 6th of May was studied; this timetable showed 60 flights departing from Newcastle Airport across the duration of the day. Similarly Sunday the 5th of May contained 61 flights and Tuesday the 7th May contained 60. These flights all had a fairly similar distribution of flights across the day, i.e. eight flights between 6:00 and 7:00 am, earliest flight between 5:00 and 6:00 am and last flight between 22:00 and 23:00.

An assumption that every plane that leaves the airport is full of bags that have come through the system was made. To find the number of bags, now having the number of flights from the airport in a day, it was necessary to find the number of passengers on each flight and the amount of cargo that each plane would travel with. To gain these statistics the fleet of a popular airline company was studied. EasyJet has a fleet of 198 airplanes, 138 or 70 % of this fleet being the Airbus

A319 airplane [9]. The A319, which has cargo capacity of 5 LD3 containers and a passenger capacity of 124 [10], is therefore a suitable model to treat each flight from Newcastle Airport as. Therefore, multiply the number of passengers per flight by the number of planes that leave a day.

$$60 \text{ flights} \times 124 \text{ passengers} = 7440 \text{ bags per day}, \quad (1)$$

$$\frac{7440 \text{ bags per day}}{24 \text{ hours}} = 310 \text{ bags processed an hour}. \quad (2)$$

This will be the traffic of bags under the stated assumptions if every person on every flight had a bag that they choose to send through the proposed system.

5.2 The Collection Hub

5.2.1 Location of the Collection Point

This is the origin of the bags' journey within the system. The location of the collection hub for this system has been set at Newcastle's Haymarket. The location of the collection hub is critical to how well it will facilitate the passenger. Haymarket is situated at the end of the busy high street Northumberland Street, centre of the city. It is also a busy changeover station for the Newcastle Metro service. This means that a large volume of people will travel past the Haymarket, it is also reasonably accessible with nearby roads and multi-storey car parks. These factors make Haymarket the ideal location for the bag collection in the system. The only complications that may arise would be infrastructure developments in such a busy area.

5.2.2 Baggage Collection

Passengers are required to drop each bag off to the Haymarket hub to have them sent through the system. There will therefore be a need for a means of collecting these bags. This is done using one large area with different service points to accommodate to the large flow of customers. An assumption is made that it will take approximately 5 min to process a customer's bag. This results in the following calculation to calculate the number of service points required.

$$\frac{310 \text{ bags an hour}}{60 \text{ min an hour}} \times 5 \text{ min per bag} \approx 26 \text{ service points}. \quad (3)$$

The 26 service points required is split up into 10 service points with a human point of contact and 16 points which are automated. These provide a slightly faster option for those who do not need assistance with the process.

5.3 Freight Trains, Containers and Cradles

5.3.1 LD3 Containers

The LD3 containers that are carried by airplanes have also been used in the transit of bags from the collection point to the airport. Using these containers allows consolidation of the bags at after bag sorting at the Haymarket and allows cargo to be moved about with greater ease than would be possible with loose bags.

These containers are of the following overall dimensions height 1.63 m, width 1.54 m and length 2.01 m.

Using the containers to transport consolidations of 25 bags allows containers of approximately 500 kg to be handled by machinery before the track. This means there is less labour intensive lifting of bags on and off trains, which results in faster loading and unloading times (Fig. 7).

5.3.2 Loading and Unloading Freight Trains

The system was designed with the aim to transport 15 containers per train. This means loading and unloading 15 containers at both Haymarket and the airport. It is therefore ideal to have these 15 containers placed into one freight cradle structure. This cradle structure needs to support the 7.5 tons that the 15 containers produce together. Using one cradle on each freight train allows cradles to be prepared before a freight train arrives at the loading/unloading station, again reducing time spent loading or unloading.

The cradles of large mass are required to be lifted off a freight train whilst empty and replaced with a loaded cradle. To allow this loading and unloading of such heavy goods, automation is necessary. An option that would be very suitable is the use of a gantry crane. A gantry crane allows an empty cradle to be removed and replaced with a loaded cradle with ease.

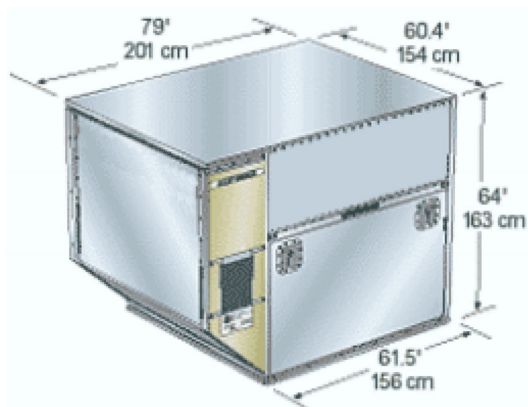


Fig. 7 LD3 container [17]

5.3.3 Freight Trains

The number of freight trains that the system required originates from a few assumptions. It was assumed that for every flight there would be 5 containers to be transported. The type of freight train that has been looked at to be used is the British Class 66 due to its overwhelming popularity within the UK rail industry.

5.3.4 The Service

As previously discussed, Sect. 5.3 the client, there are two main groups of customers for the system, these are the business passengers and those travelling for leisure. The design is less likely to fail if the bags are not always being dropped off just before they need to be processed through the entire system.

To avoid this situation the service options to the customer are split into immediate processing of the bag, processing within 5 days or within 14 days. Using these three service options helps reduce the amount of bags needing immediate processing. Incentivising the 5- and 14-day options for with reduced rates ensures that more people drop their bags many days in advance, keeping the system from suffering a large spike in baggage traffic. With reduced rates for later deliveries the system also appeals to groups of people who can afford to drop their bag off earlier, taking another concern off their minds on the day of their travels.

5.3.5 Storage and Logistics

There are three different storage areas, the 14-day storage, the 5-day storage area and the 24-h storage facility. It can be assumed that there is a maximum capacity of 7440 bags in the 24-h facility, as this is the most the system can process. To store such volumes of baggage, a level of automation is beneficial. The bags are stored using racking and crane systems. Vanderlande offer a system called 'BAGSTORE', this system stores the bags individually on large shelf structures that span across a warehouse. These are 10 rows of shelves which are 10 high and 75 long. This therefore accommodates the storage of 7500 bags, more than are required to be stored a day. The bags are retrieved by automated cranes which pull the bags out of their shelves to be transported to the appropriate LD3 container. This storage is also used in the 5- and 14-day storage rooms, of much smaller volumes than the 24-h facility.

Transporting the bags to, around and from these storage rooms is another important aspect of the design. It is most desirable to use automated options again here due to the volume of bags to be transferred. There are a couple of options for this transfer of baggage; there is a standard

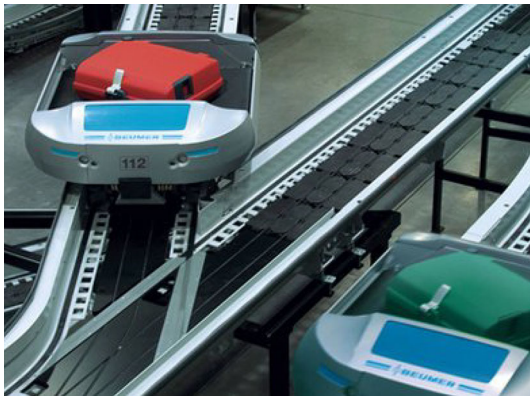


Fig. 8 BEUMER AUTOVER [18]



Fig. 9 Vanderlande BAGSTORE [19]

option of using conveyor belts and there is also the more expensive option of using a system such as BEUMER AUTOVER. An independent carrier system (ICS) such as the BEUMER AUTOVER offers benefits in control and tracking of the individual bags (Figs. 8, 9).

The collection hub is best split into two areas, the unloading/loading area and the storage areas (Fig. 10). The bags originate from the collection point. From here they move to the 14-day storage, the 5-day storage or the 24-h storage. The 14- and 5-day storage options both have means of moving bags through to the next duration storage, i.e. the 14-day storage moves to 5 day storage and the 5-day storage to 24-h storage at the appropriate times. The majority of bags from the collection point move directly to the 24-h storage, bypassing the 5-day and 14-day options. This system means that the bags are always moving towards their final destination within the hub, the track where they are placed onto the train.

Aside from the storage facilities there is the loading/unloading area. This is an area where there is a constant circulation of LD3 containers. These containers start being filled with bags moved out from the 24-h storage and are

placed onto the freight cradles when full. This loaded cradle will then wait on the cradle track. When a freight train enters the hub, the cradle of empty containers is removed by the gantry crane and placed on the cradle track, the loaded cradle is then moved up the cradle track and loaded onto the train by the same gantry crane. Once the train leaves, the empty containers are removed from the cradle, which then returns to the original position and is circulated back to the LD3 loading bay to await more bags for the next train.

6 SIMUL8, Event-Based Simulation Modelling

6.1 Simulation Modelling

To analyse the performance of the designs they were created using SIMUL8. The simulation models are created to mimic the most realistic behaviour possible. The designs are run in their optimal state. Therefore, there are no delays of trains or other possible real-time problems for the model to simulate. These models are used not only as a measure of their performance, with regard to track utilisation, but also as a validation that the system can be created and can function. The freight trains placed onto the system are done so without interfering with any of the passenger trains; this is one of the key rules of design employed (Table 1).

There are four scenarios modelled using SIMUL8. These consist of one passenger only system, a scenario where freight trains are placed on the system only where required based on flight times from Newcastle Airport and two other scenarios where the aims are to increase track utilisation by saturating the system with freight trains.

6.2 Start Points

Each model has multiple start points which are the locations where the trains enter the system. There must be a unique start point used for each group of trains, i.e. South Gosforth, Regent Centre and regular passenger trains.

The start points control the input of work items into the system i.e. the origin of trains in the model. These can be input with a frequency, mathematical functions or as in this case using a schedule sheet (Figs. 11, 12).

6.3 Work Items and Labels

Each simulation model requires work items, the trains in these cases. Though there is only one work type used in the proposed designs, this work item is shared across four different trains: regular passenger trains, freight trains, trains that stop at Regent Centre and trains that stop at South Gosforth. To split the trains into these four different

Fig. 10 A Sketch of the collection hub

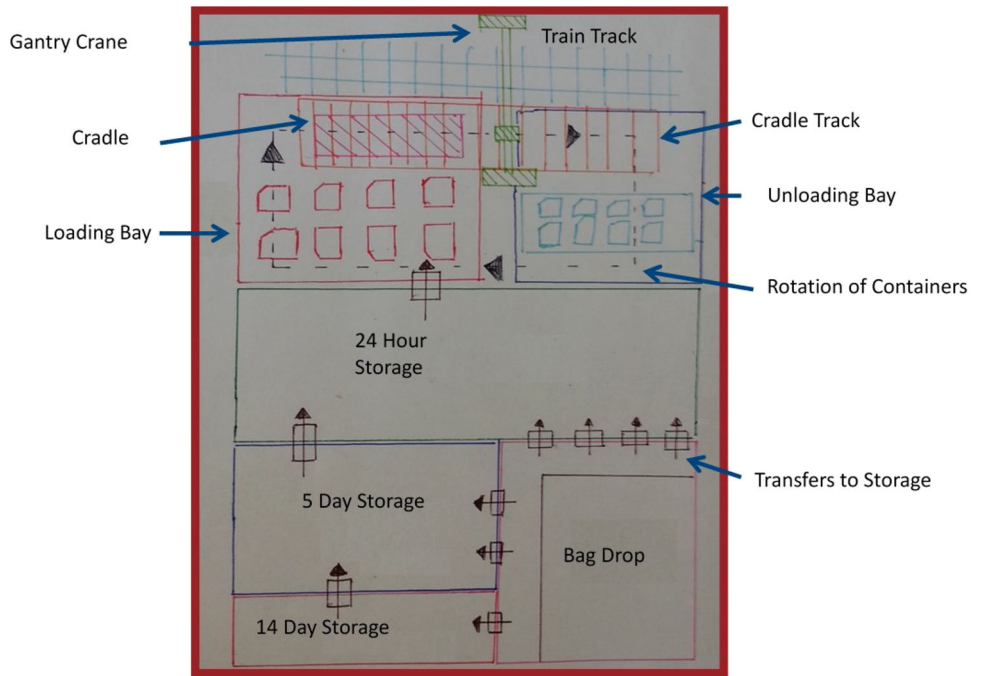


Table 1 Scenarios

Scenario 0	Passenger service only
Scenario 1	Passenger + freight trains when required
Scenario 2	Passenger + freight trains to increase track utilisation 1
Scenario 3	Passenger + freight trains to increase track utilisation 2

groups a different label value is assigned to each of the trains from their start points. These labels allow the trains to be routed differently later in the model by activities (Fig. 13).

6.4 Schedule Sheets

Each start point has a unique schedule. These schedules can be created externally on a software such as excel and imported via the paste option to SIMUL8. The requirements of the schedule sheet are that a time and quantity (batch size) is stated. There are rules to how the trains are ordered in the schedule sheet, such as the trains must be entered into the sheet chronologically (Fig. 14).

6.5 Activities

The activities are the most used function in the simulation models. These activities are used as both the stations as well as the tracks between stations. Activities apply an action to the work items that travel through them, for instance making them wait for a fixed amount of time (Fig. 15).

6.6 Routing Out

Each activity within a model has a routing out option, used when there is more than one exit from an activity that work items can travel down. These routing out options can use many forms such as mathematical functions or circulate,

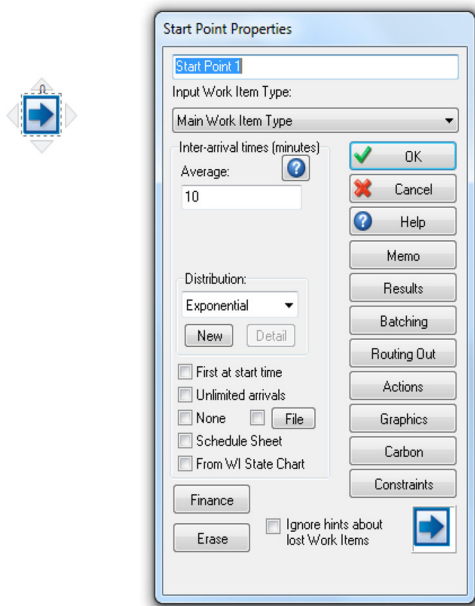


Fig. 11 Start point

Fig. 12 SIMUL8 labelling

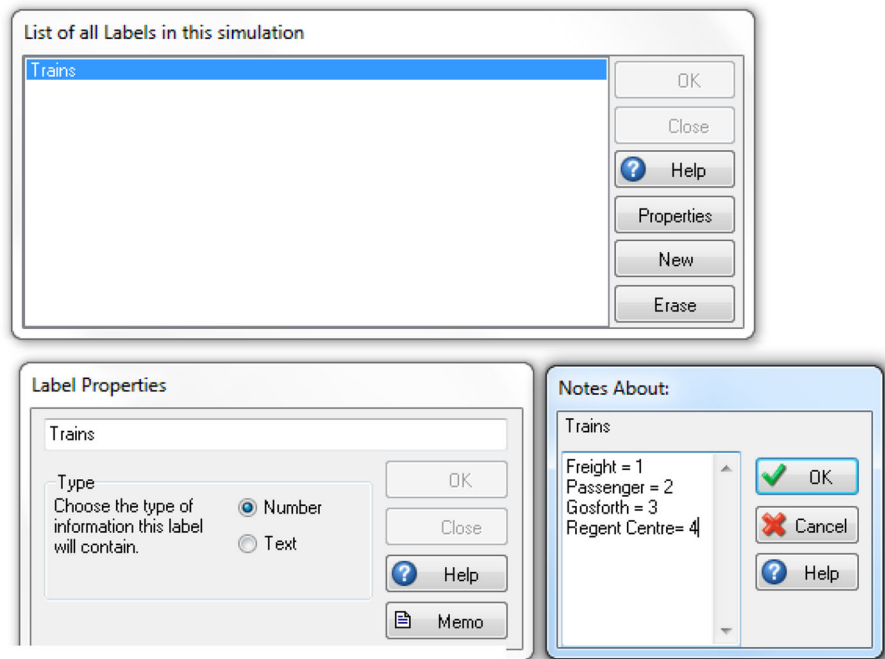
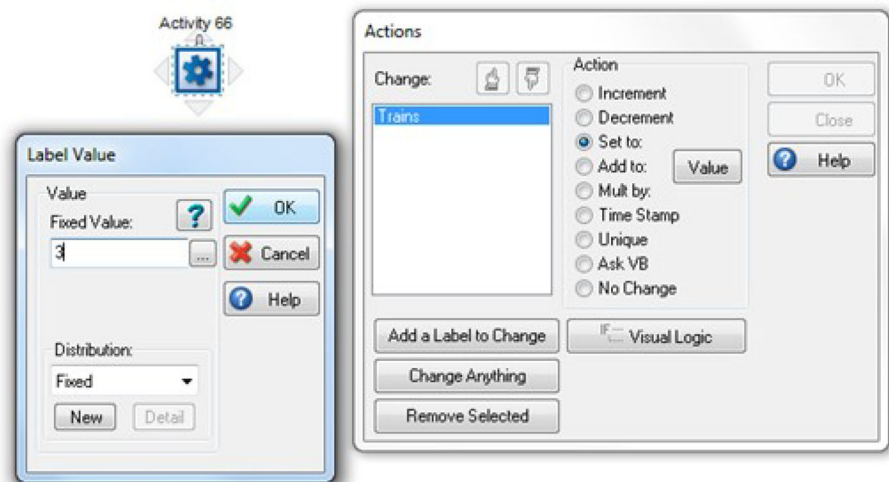


Fig. 13 SIMUL8 work items



which releases work items in the same manner that cards are dealt with (Fig. 16).

The option used to control the journeys of the different trains is Label, allowing the user to control each train by the value that they were assigned at their start points.

6.7 Activity Bypasses

Freight trains and passenger trains will use the same metro line from the Haymarket to the airport, however the freight trains need not stop at stations as the passenger trains do. As an option to treat the two different groups differently by an activity was not found, bypasses were created which

exist as activities which move the freight trains to the next activity (track) whilst making passenger trains move to the activity before the track (the station).

As it can be seen from Fig. 17 the freight trains, which are set to value 1, will bypass Callerton Parkway and move straight to the track towards Bank Foot. This is not for the case for passenger trains, value 2, which will be sent to the Callerton Parkway station to wait their duration. It is important to note that these activities, which are attached to every station in the model, have a processing time of 0 and therefore do not interfere with the model in anyway. These activities only act as a controller for the trains moving through the model.

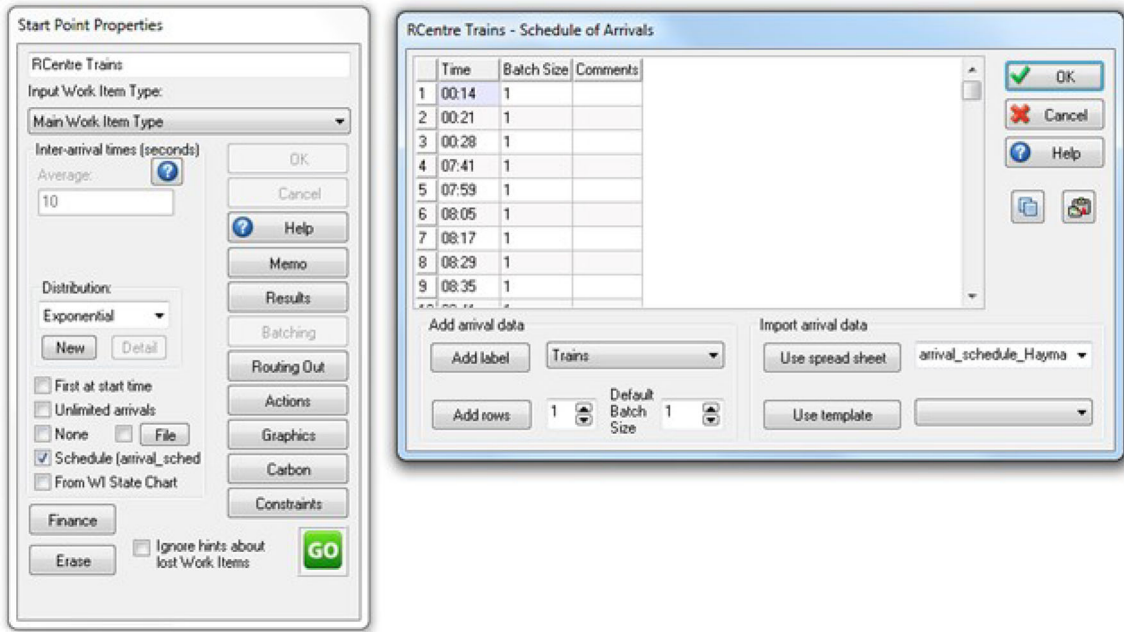


Fig. 14 SIMUL8 schedule sheets

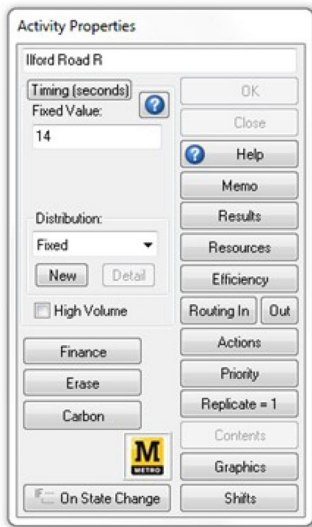


Fig. 15 SIMUL8 activities

6.8 Clock Settings

The clock settings are an important part of the simulation model. A unit of time for the model is chosen here, seconds being the most suitable for the design models as the transit times and station times are recorded in seconds. A warm-up period is also chosen here. This is a period of time which can be used to move the system into the middle of its duration before starting to take measurements.

The clock settings also involve choosing a start time and duration for each day. To measure the utilisations of

tracks on the metro line it is essential that the duration be 24 h as freight trains may be implemented onto the system over 24 h, the start time of each day is not as important so midnight was chosen. The final important option from clock settings is the duration that the simulation will run for (Fig. 18). To analyse the system it is best to run it over the course of a week, as there will be many more trains run over the system this way than if just a day were used.

6.9 Utilisations and Blockages

Each activity will produce a result for the percentage of time that the activity was in use and not in use. This is the percentage of time that there is a train on the track as opposed to the track being empty. This is how data have been collected for the utilisation of each track.

The system can also be validated through the results produced by all of the activities. The results show a percentage of time that the activity was blocked and a maximum number of work items (Fig. 19). If the maximum is 2 it means that two trains have been on the track together at the same time, this would mean the system has not worked as there should never be two trains on the same track. Similarly if the blockage value is not 0 it means there has been a reason why the work item could not leave the activity, normally caused by the next item having a capacity limit preventing work items entering. This would also be an indicator of the system failing.

Fig. 16 SIMUL8 routing out

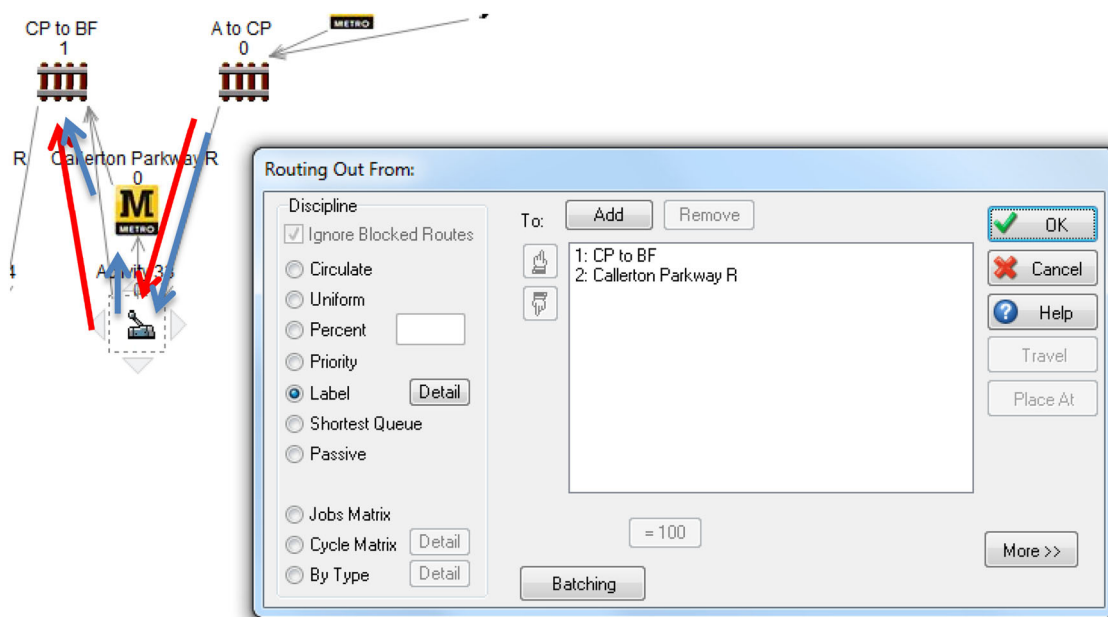
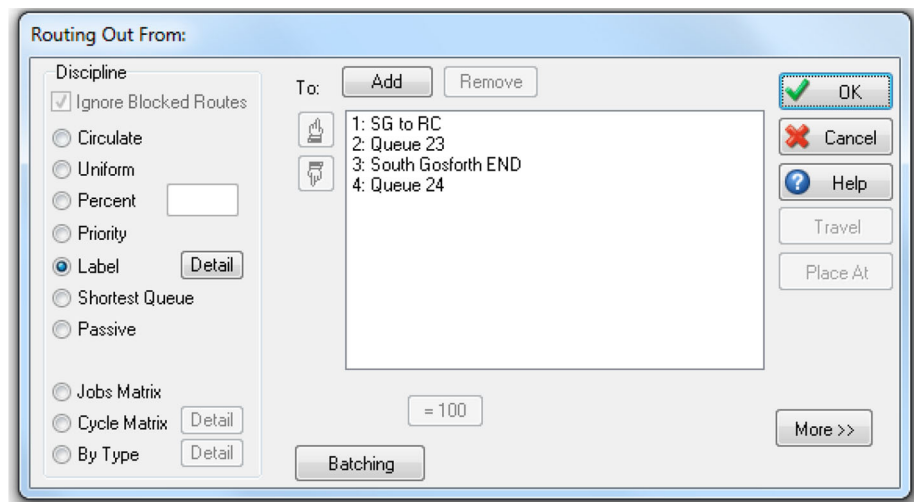


Fig. 17 Model bypasses, blue arrow shows passenger route and red arrow shows freight route

6.10 End Points

End points record max, min and average transit times that work items take to reach the end of the system. These points also count the number of work items that made it through the system to the end (Fig. 20).

7 Applications of Modelling

7.1 Scenario 0

The first step in modelling the new designs was to create a simulation model for the regular metro system between Haymarket and the airport. This would then be validated

and have its utilisations of tracks recorded. There are no freight trains on this model.

To make the simulation model as close to the reality as possible it was essential to implement the correct times for transit of the trains between stations, as well as the correct time that a train would spend waiting at a station. The times used in the model originate from readings taken by Marinov and Motraghi [4] (Tables 2, 3).

7.1.1 Schedule

The schedule for the trains implemented onto the system is identical to the online timetable that metro provides for trains going towards the airport from the Haymarket [11].

Fig. 18 SIMUL8 clock properties

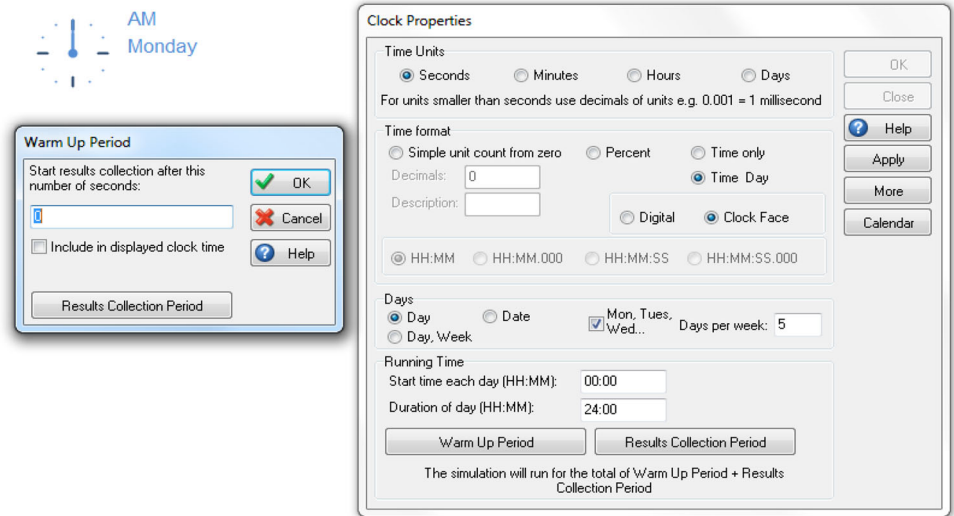
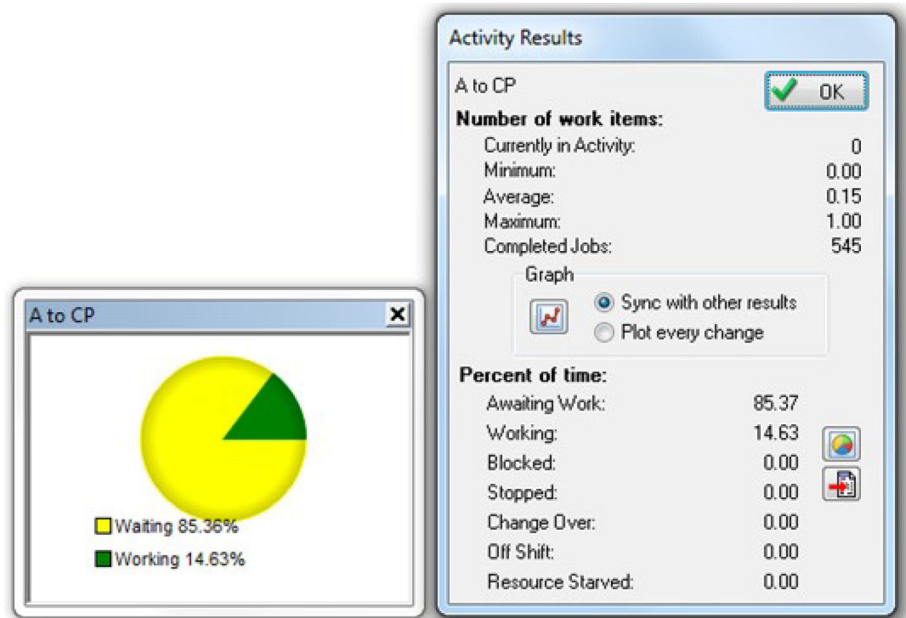


Fig. 19 Activity results



This is split up into three different start points in the model: the trains going to the airport, trains ending at Regent Centre and trains ending at South Gosforth. Each start point has its own timetable for the different groups of trains (Table 4).

The addition of the freight trains to the system has been done so without interfering with the passenger system. The passenger trains therefore control where freight trains can be added to the system during the day.

7.1.2 The Model

The simulation model as shown in Fig. 21 emulates the behaviour of the metro train system. There are 3 start points active for South Gosforth, Regent Centre and Newcastle Airport trains. Once the airport passenger trains get to the airport they wait and return down the bottom line which is a mirror image of the top line (Haymarket to Callerton Parkway) (Tables 5, 6).

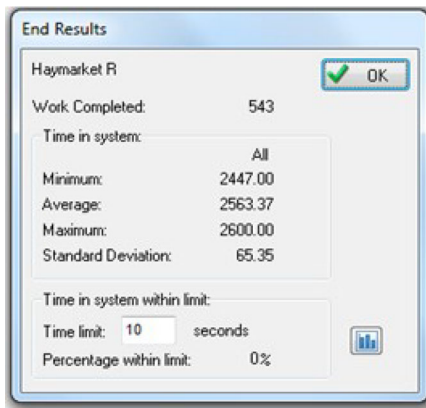


Fig. 20 End results

7.1.3 Validation

As this is the most basic model (no freight trains) to be presented it is crucial that it is validated to check that the model does indeed function as the real world network does. There are two means of validation performed on the model. Firstly the results of the end line are analysed. The total time that a passenger train should take is the total waiting time in all the stations up to the airport, multiplied by two for the return journey, plus the time spent at airport and all the times between stations.

As it can be seen from the end of line results, Fig. 22, the minimum, maximum and average time are all 2600. This then validates the model as it shows the exact amount of time each train took that hand calculations have shown it should take.

Table 2 Station wait times

Station	Recorded times spent at station (seconds)			Average time (to the nearest second)
Airport	232	259	356	282
Callerton Parkway	14.5	15.1	16.8	15
Bank Foot	11.4	12.7	16.2	13
Kingston Park.	11.5	17.1	17.8	15
Fawdon	10.8	15.3	16.5	14
Wansbeck Road	13.4	14.2	15.7	14
Regent Centre	12.7	13.6	18.4	15
South Gosforth	12	17.4	25.4	18
Ilford Road	11	15.1	16.6	14
West Jesmond	12.9	18.5	19.8	17
Jesmond	17.1	17.4	18.2	18
Total				435

Table 3 Train travel times

Stations		Recorded travel times (seconds)			Average travel time (to the nearest second)
From	To				
Airport	Callerton Parkway	109	115	123	116
Callerton Parkway	Bank Foot	156	163	171	163
Bank Foot	Kingston Park	66	68	77	70
Kingston Park	Fawdon	103	113	116	111
Fawdon	Wansbeck Road	56	65	67	63
wans beck Road	Regent Centra	30	47	69	49
Regent Centre	South Gosforth	101	109	117	109
South. Gosforth	Ilford Road	61	68	98	76
Ilford Road	West Jesmond	41	42	46	43
WestJesmond	Jesmond	89	93	103	95
Jesmond	Hay market	99	116	117	111
Total				1006	

Table 4 Airport timetable

Timetable to a airport										
06:02	07:59	08:53	10:08	12:08	14:08	16:08	17:17	18:19	20:18	22:48
06:25	08:05	08:56	10:20	12:20	14:20	16:20	17:20	18:28	20:33	23:03
06:47	08:08	09:08	10:32	12:32	14:32	16:32	17:23	18:31	20:48	23:18
06:58	08:17	09:20	10:44	12:44	14:44	16:35	17:32	18:42	21:03	23:33
07:08	08:20	09:32	10:56	12:56	14:56	16:44	17:35	18:53	21:18	23:48
07:20	08:29	09:35	11:08	13:08	15:08	16:47	17:44	19:05	21:33	23:59
07:32	08:32	09:44	11:20	13:20	15:20	16:56	17:47	19:18	21:48	REPEAT
07:41	08:35	09:47	11:32	13:32	15:32	16:59	17:56	19:33	22:03	
07:44	08:41	09:53	11:44	13:44	15:44	17:05	18:07	19:48	22:18	
07:56	08:44	09:56	11:56	13:56	15:56	17:08	18:16	20:03	22:33	

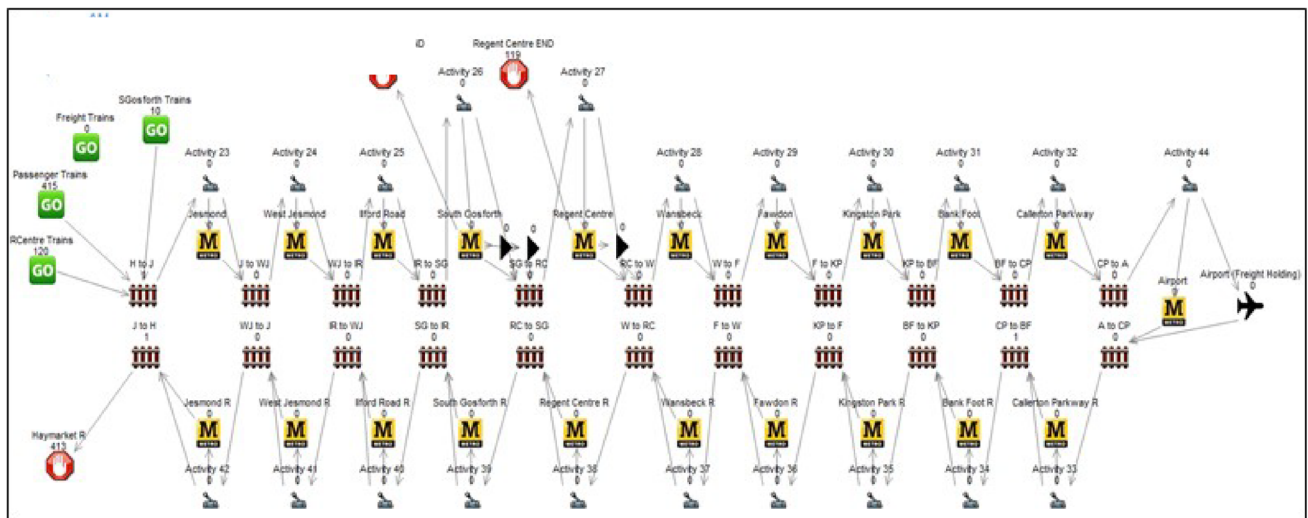


Fig. 21 Simulation model: screen-shot, Scenario 0

Table 5 South Gosforth timetable

Timetable to South Gosforth
09:53
18:28
REPEAT

Table 6 Regent Centre timetable

Timetable to Regent Centre		
00:14	08:41	17:23
00:21	08:53	17:35
00:28	09:35	17:47
07:41	09:47	18:16
07:59	16:35	23:48
08:05	16:47	23:59
08:17	16:59	REPEAT
08:29	17:05	
08:35	17:17	

The results of each activity can also be analysed. If at any point there is a value other than 0 for percentage of time blocked, then the trains are clashing with one another on the track and the model needs to be adjusted.

Time spent at stations + time spent on tracks

+ time spent at airport = transit time

$$((435 - 282) \times 2) + (1006 \times 2) + 282 = 2600 \text{ s}$$

(4)

7.2 Scenario 1

This is the first baggage transfer system proposed. The intentions of this system are to facilitate the airport users. The quantity of trains is driven by the number of flights from Newcastle Airport [12], as shown in Table 7.

A business traveller may have a short-notice flight booked and would be required to drop his baggage off shortly before embarking upon his journey. This system

Fig. 22 Scenario 0 end and activity results

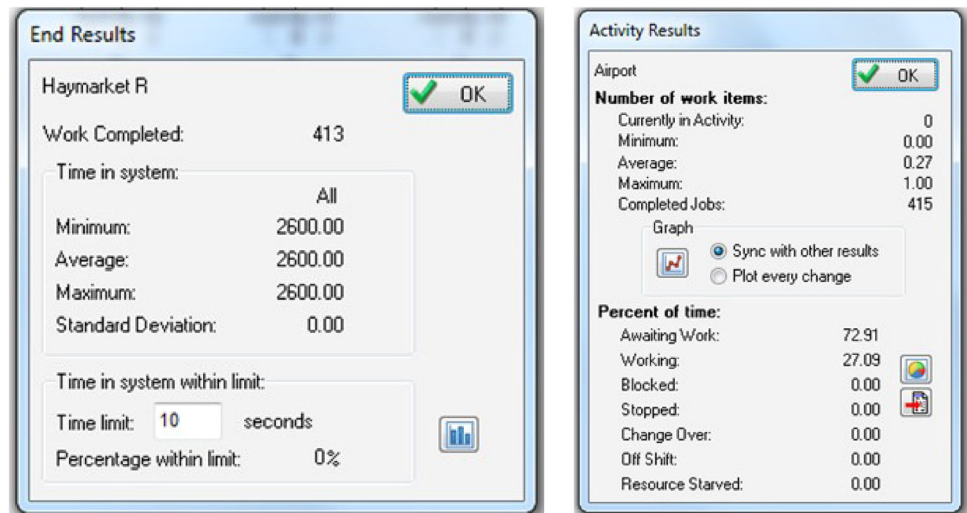


Table 7 Freight trains for flights [12]

Times		Departures	
From	To	Airplanes	Freight trains
03:00	04:00	0	1
04:00	05:00	0	3
05:00	06:00	1	3
06:00	07:00	8	1
07:00	08:00	9	2
08:00	09:00	3	1
09:00	10:00	5	2
10:00	11:00	1	1
11:00	12:00	4	1
12:00	13:00	1	1
13:00	14:00	3	1
14:00	15:00	3	2
15:00	16:00	2	2
16:00	17:00	4	1
17:00	18:00	4	1
18:00	19:00	2	2
19:00	20:00	2	0
20:00	21:00	4	1
21:00	22:00	0	0
22:00	23:00	1	0
		Total	26

accommodates the short notice with fast delivery of a bag to the airport to catch the same flight as the passenger. To get these bags onto the same flight as the passengers it would be essential that they drop their bags off at the collection point in time for a freight train that leaves two hours before the airplane it is intended for. For example if an airplane leaves within the hours of 5:00 and 6:00 a

freight train will be required to leave between 03:00 and 04:00. As every airplane carries 5 LD3 containers and each train carries 15 it is clear that for every 3 flights in an hour there will be a freight train required 2 h before.

7.2.1 Schedule

The freight trains enter the line at any point within their designated hour that they do not interrupt the passenger trains. Table 8 shows the proposed schedule of freight trains, the schedule of passenger trains remains unchanged. The total of 26 freight trips a day equates to the maximum transfer of 390 containers a day or 9750 bags.

7.2.2 The Model: Freight Trains Airport Holding

The only changes to the model shown in Fig. 23 from the passenger only model is the addition of freight trains to the system and the use of the ‘Airport (Freight Holding)’ which in the previous model was not routed to from Activity 44.

The timing that a freight train spends in the airport holding is what controls the separation of freight trains and passenger trains from the airport to Haymarket. The time has been chosen to re-sync the difference between freight trains and passenger trains that existed when they originally departed Haymarket.

$$\begin{aligned}
 &\text{Difference between freight and passenger after airport} \\
 &= \text{station waiting times} + \text{passenger airport waiting time} \\
 &153 \text{ s} + 282 \text{ s} = 435 \text{ s} \tag{5}
 \end{aligned}$$

It is therefore essential that each freight train waits for 435 s, 7 min and 15 s, at the airport to ensure that the difference due to transit times between the passenger trains

Table 8 Scenario 1 timetable

Scenario 1 (departure times)	
03:00	11:02
04:00	12:02
04:15	13:02
04:30	14:02
05:00	14:15
05:15	15:02
05:30	15:15
06:10	16:02
07:05	17:14
07:26	18:04
08:26	18:25
09:02	20:00
09:15	REPEAT
10:02	

Train Separations			
Type	Cause	Calculation (Seconds)	Spacing rounded up (min)
Freight - Freight	Airport holding	435	8
Freight - Passenger	Callerton Parkway - Airport	(1159 - 1006) +116 = 269	5
Passenger - Freight	Callerton Parkway - Bank Foot	163	3

Fig. 24 Train separations

and freight trains is removed from the equation, and the schedules are re-synched.

There are rules to the timings that must exist between freight trains and passenger trains. These are explained in Fig. 24.

This means that freight train to freight train separation must be 8 min or more, passenger trains must leave at least 5 min in advance of freight trains and freight trains must leave at least 5 min in advance of passenger trains.

7.2.3 Validation

The same validation techniques can be used as shown for Scenario 0. The transit times are checked and the activities are checked for blockages.

Each freight train takes 2447 s to complete its transit from Haymarket to airport and back again.

$$\text{Freight transit time} = (1006 \times 2) + 435 = 2447 \quad (6)$$

Transit times calculated over the course of a day are as follows:

$$\begin{aligned} &\text{Average transit time} \\ &= \frac{(26 \text{ freight} \times 2447 \text{ s}) + (81 \text{ passenger} \times 2600 \text{ s})}{(81 + 26) \text{ trains}} \quad (7) \\ &= 2562.82 \text{ s} \end{aligned}$$

Results obtained from simulation show the same figure for the average (Fig. 25).

7.3 Scenario 2

Scenario 2 is created to fulfil the same purposes as Scenario 1 with an additional function. Scenario 2 attempts to saturate the system using the same infrastructure. The reason for saturating the system is to see what the maximum capacity of the system is. This is done by adding freight

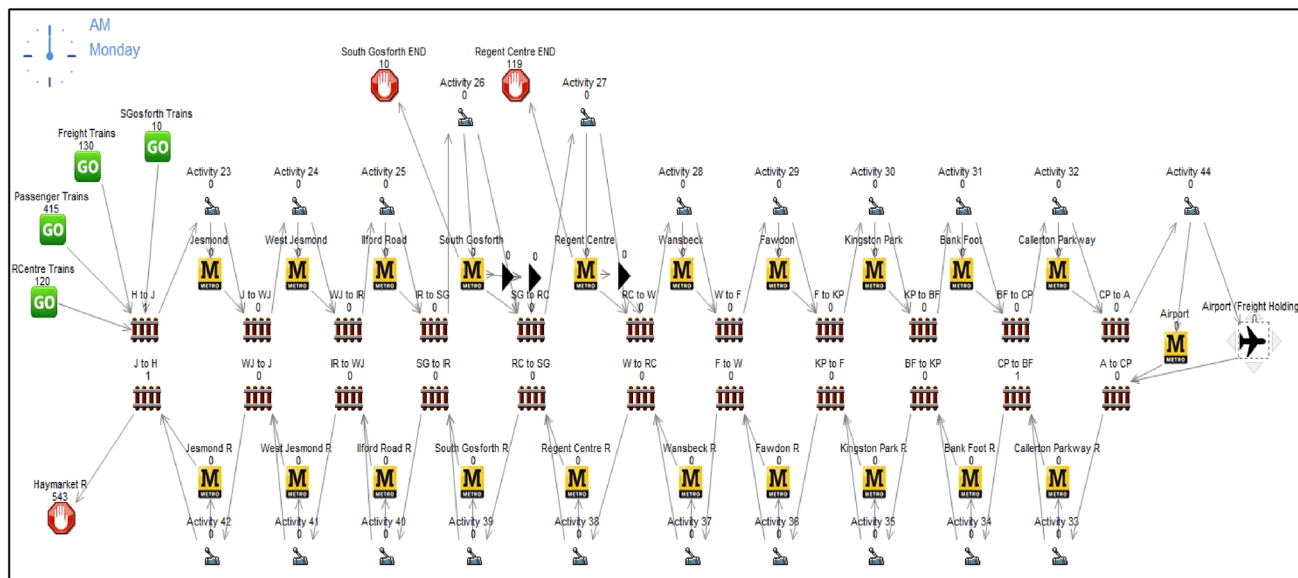


Fig. 23 Scenario 1 model

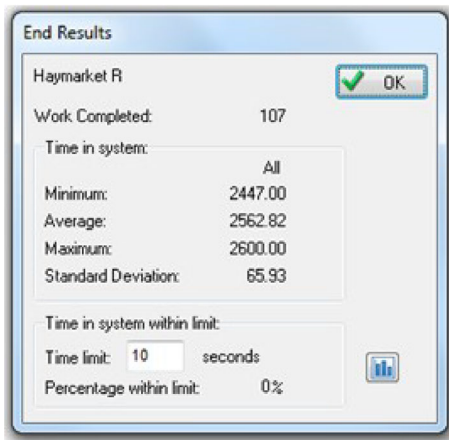


Fig. 25 Scenario 1 end results

trains to the system overnight and occasionally in gaps during the day.

7.3.1 Schedule

The number of freight trips that have been added to the system since Scenario 1 is 91, resulting in a total of 117 freight trips. For Scenario 2 the timetable is shown in Table 9. Overnight when the track is not in use the system can run 7 freight trains an hour. The factor that limits the number of freight trains that can be added is the 8 min separation between each train.

The 117 freight trips equate to the maximum transfer of 1755 containers a day or 43875 bags.

Table 9 Scenario 2 timetable

Scenario 2 (departure times)										
00:05	02:00	03:32	05:08	07:03	09:40	12:13	14:37	17:13	19:40	22:25
00:32	02:08	03:40	05:16	07:13	10:01	12:25	14:49	17:29	19:54	22:40
00:40	02:16	03:48	05:24	07:25	10:13	12:37	15:01	17:40	20:09	22:55
00:48	02:24	04:00	05:32	07:37	10:25	12:49	15:13	17:53	20:24	23:10
01:00	02:32	04:08	05:40	07:49	10:37	13:01	15:25	18:03	20:39	23:25
01:08	02:40	04:16	05:48	08:13	10:49	13:25	15:37	18:13	20:55	23:40
01:16	02:48	04:24	06:07	08:25	11:01	13:37	15:49	18:25	21:10	23:54
01:24	03:00	04:32	06:15	08:47	11:13	13:49	16:01	18:37	21:25	REPEAT
01:32	03:08	04:40	06:30	09:01	11:37	14:01	16:25	18:48	21:40	
01:40	03:16	04:48	06:38	09:13	11:49	14:13	16:40	19:00	21:55	
01:48	03:24	05:00	06:52	09:25	12:01	14:25	16:52	19:11	22:10	

Table 10 Scenario 3 timetable

Scenario 3 (departure times)										
00:04	01:24	02:24	03:24	04:24	05:24	07:13	10:49	14:13	17:29	20:55
00:08	01:28	02:28	03:28	04:28	05:28	07:25	11:01	14:25	17:40	21:10
00:32	01:32	02:32	03:32	04:32	05:32	07:37	11:13	14:37	17:53	21:25
00:36	01:36	02:36	03:36	04:36	05:36	07:49	11:37	14:49	18:03	21:40
00:40	01:40	02:40	03:40	04:40	05:40	08:13	11:49	15:01	18:13	21:55
00:44	01:44	02:44	03:44	04:44	05:44	08:25	12:01	15:13	18:25	22:10
00:48	01:48	02:48	03:48	04:48	05:48	08:50	12:13	15:25	18:37	22:25
00:52	01:52	02:52	03:52	04:52	05:52	09:01	12:25	15:37	18:48	22:40
00:56	01:56	02:56	03:56	04:56	05:56	09:13	12:37	15:49	19:00	22:55
01:00	02:00	03:00	04:00	05:00	06:07	09:25	12:49	16:01	19:11	23:10
01:04	02:04	03:04	04:04	05:04	06:15	09:40	13:01	16:25	19:40	23:25
01:08	02:08	03:08	04:08	05:08	06:30	10:01	13:25	16:39	19:54	23:40
01:12	02:12	03:12	04:12	05:12	06:38	10:13	13:37	16:52	20:09	23:54
01:16	02:16	03:16	04:16	05:16	06:52	10:25	13:49	17:03	20:24	REPEAT
01:20	02:20	03:20	04:20	05:20	07:03	10:37	14:01	17:13	20:39	

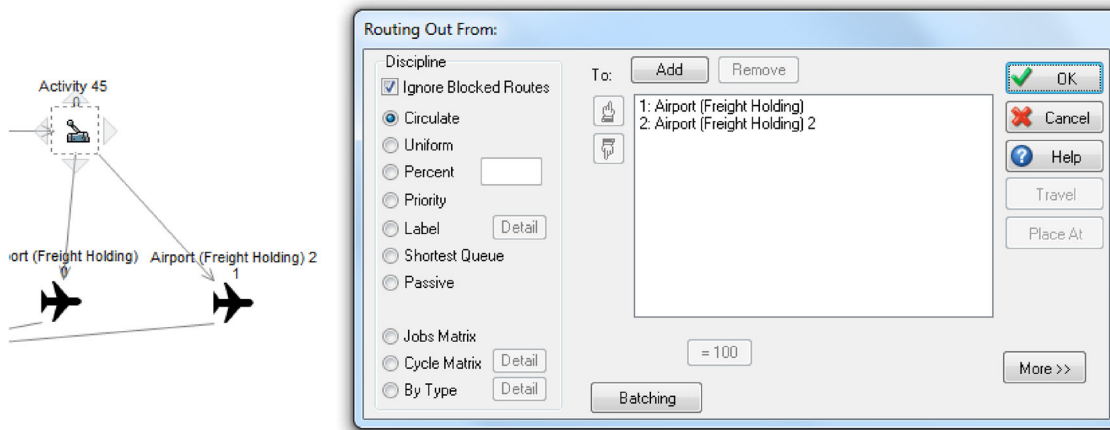


Fig. 26 Scenario 3 model

Table 11 All utilisations

Utilisation %				
Section	Scenario 0	Scenario 1	Scenario 3	Scenario 3
H-J	13.99	17.33	29.02	34.93
J-WJ	11.96	14.82	24.83	29.89
WJ-1	5.41	6.71	11.24	13.53
l-SG	9.57	11.86	19.86	23.91
SG-RC	13.47	16.75	28.22	34.02
RC-W	4.71	6.18	11.33	13.94
W-F	6.05	7.95	14.57	17.92
F-KP	10.66	14.00	25.67	31.58
KP-BF	6.72	8.83	16.19	19.91
BF-CP	15.66	20.56	37.69	46.37
CP-A	11.14	14.63	26.83	33.00
A-CP	11.14	14.63	26.80	32.97
CP-BF	15.63	20.54	37.63	46.31
BF-KP	6.71	8.81	16.16	19.88
KP-F	10.64	13.98	25.62	31.53
F-W	6.04	7.93	14.54	17.89
W-RC	4.70	6.17	11.31	13.92
RC-SG	10.45	13.73	25.15	30.95
SG-I	7.28	9.57	17.52	21.57
l-WJ	4.12	5.41	9.91	12.20
WJ-J	9.10	11.96	21.90	26.96
J-H	10.62	13.96	25.57	31.48
Max	15.66	20.56	37.69	46.37
Min	4.12	5.41	9.91	12.20
Average	9.35	12.11	21.71	26.58

7.3.2 Validation

The model is the same model used for Scenario 1, validation has only been performed to see that the new freight

trains schedule does not cause any build-ups on the system. This was done by looking for any blockages within any of the activities, of which there were none.

7.4 Scenario 3

This final scenario has been designed with the same targets in mind as Scenario 2. The key change is that this time there is a second Airport holding area on the model. This would mean that the airport holding area can now hold two trains at a time without them interfering with one another.

7.4.1 Schedule

The difference between Scenario 2 and Scenario 3 with regards to freight trips is the number that can be placed onto the system overnight. As there is a second holding area now available at the airport for freight trains, the original requirement that each train be separated by 8 min can be halved down to 4 min. This means that 15 trains can now be placed on the track every hour overnight as opposed to the seven trains that could be used in Scenario 2.

There are now a total of 163 freight trips every day to the airport; timetable is shown in Table 10. The 163 freight trips equate to the maximum transfer of 2445 containers a day or 61,125 bags.

7.4.2 The Model

The key changes to the simulation model from Scenario 2 are that there is a new schedule sheet placing many more freight trains onto the system and there is a second ‘Airport (Freight Holding)’ activity.

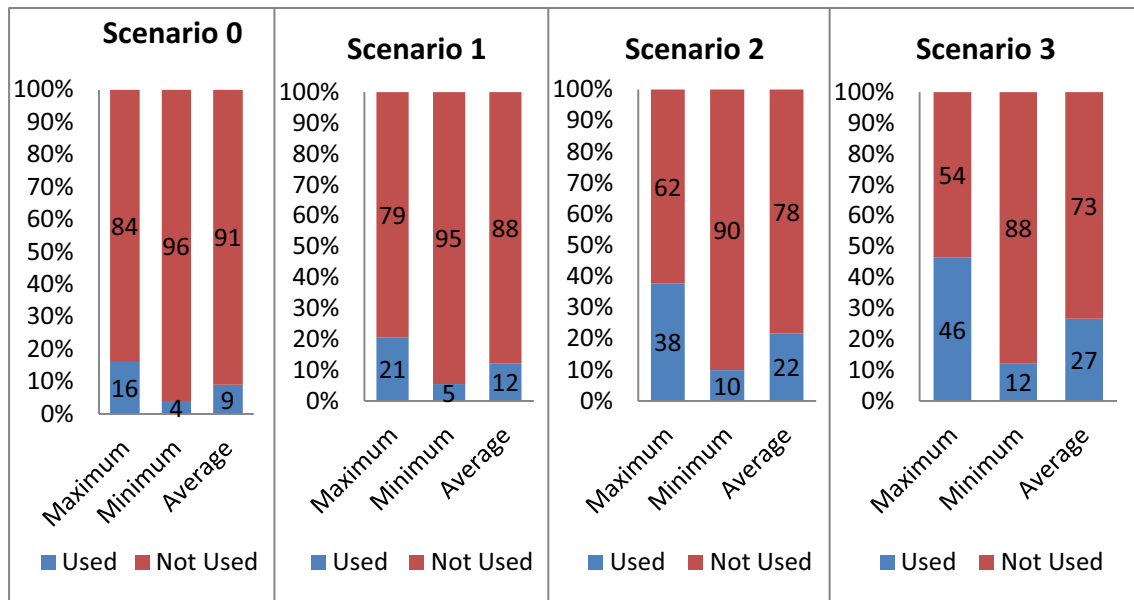


Fig. 27 Min, max and average utilisations

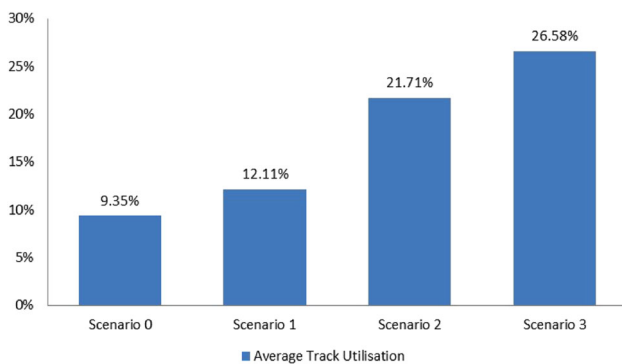


Fig. 28 Overall utilisations

For previous scenarios freight trains would move to the airport holding from Activity 44, now these trains move to a new splitting activity, Activity 45. At Activity 45, these freight trains are split using the circulate option, similar to a deck of cards being dealt, this means that the Activity exit will swap each time a train passes (Fig. 26).

Validation techniques are the same as used in Scenario 2.

8 Track Utilisations of Proposed Designs

The utilisations for each section of the line using each scenario can be seen in Table 11, Figs. 27 and 28.

There is an average difference of approximately 3 % between Scenario 0 and Scenario 1. Scenario 2 however almost doubles the utilisation of Scenario 1 and Scenario 3 further improves the work done by scenario 2 with approximately an additional 5 % utilisation. Overall, the

utilisation of Scenario 3 is nearly three times as much as that of the passenger only system.

9 Conclusions

This study presents a new design for an innovative baggage handling system which transfers baggage between a collection point, Haymarket, situated in the city centre of Newcastle-Upon-Tyne and Newcastle Airport. There are also two additional solutions which saturate the system with freight trains, resulting in greater utilisations of the metro tracks.

Validations have shown that freight trains can indeed be added to the current metro system to enable freight to be transferred between Haymarket and the airport. It was also found that this system could have a capacity large enough to accommodate every single passenger on every plane leaving from Newcastle Airport on an average day.

Exploring the opportunity to use the metro line overnight for the transit of freight trains, it was found that restrictions in scheduling freight trains in parallel to passenger trains could be avoided, leading to shorter times between freight trips and ultimately more trains per hour. A proposed system boasting a large capacity of 61,125 bags a day was validated and analysed.

10 Further Work

The proposed system could possibly be improved upon by looking at changing passenger train schedules to find an optimal schedule where additional freight trains could be

run during the day. The simulation models were all run under optimal conditions, it would also be recommended that these models be run with imperfections incorporated such as random delays and inefficiencies to see how the systems behave. Finally, it might be of interest to perform cost analyses on the three different system proposals to see if the additional costs of Scenarios 1 and 2 can be justified by their greatly increased capacities.

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