Software Package Applications for designing Rail Freight Interchanges

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Abstract

Rail freight transport has a crucial role to play in the economy, delivering significant reductions in logistics costs, pollution, and congestion. Typically, the conventional architecture and layout of the rail freight interchange constrain the capacity and performance of the whole railway system. A well-designed rail freight interchange can enhance the system performance by maximizing vehicle usage and minimizing last mile distribution cost. Therefore, the study of rail freight interchange operation is considered crucial to understand how to increase and improve the attractiveness for rail freight transport.

This thesis uses game engines to develop software packages that are used for the design of new rail freight interchanges, considering multi-stakeholder decisions drivers. A novel and modular approach has been applied with the purpose of developing and deploying simulation tools that can be used by multiple stakeholders to:

-Understand the impact of multiple-criteria decision analysis on rail freight interchange layouts;

-Use a genetic algorithm to identify the most suitable components of the future interchange to be designed, considering the multi-stakeholders' priorities;

- Quickly enable the design of a wide variety of rail freight interchanges from the information selected by a decision maker in a computer-based user-friendly interface.

This research has proposed a framework for software development. Three case studies are used to illustrate adaptability of a number of applications for different scenarios. The findings of the research contribute to a better understanding of the impacts of the multiple stakeholder's decisions on rail freight interchange designs.

Key words: Rail Freight Interchanges, Multi stakeholders decision, genetic algorithm

Dedicated to my wife Cristina and my kids who loved, supported and encouraged me all the time.

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Chapter 1: Motivation

This chapter introduces the importance of rail freight transport and the role of rail freight interchanges. It presents the objectives of the thesis, its' scientific contribution, and thesis organisation.

1.1 Problem Formulation

The rail freight system has a significant impact on the economy. To study the interrelation between the elements of the rail freight system, it should be decomposed into subsystems (Straussfogel and Von Schilling 2009),. Each element in a rail freight system is designed to make the rail operation viable.

As for intermodal transport, the number of decision makers involved in the transport increases the complexity of the operation.

Considering the importance of the rail freight interchanges, the focus of this research work is dedicated to the study of the subsystem *interchange* and the development and implementation of software packages that can be used to design it.

1.2 Thesis Objective

The objective of this thesis is: to understand the role of the multi-stakeholder decision drivers and to help develop decision-making support tools to assist multiple decision makers involved in rail freight transport, particularly for the next generation of interchange to meet the multiple stakeholder's requirements (e.g., efficiency, operational cost, environmental impact, transhipment costs). Therefore, this thesis examines four main research questions:

1- How do the changes in the global market for freight impact on the need for rail freight interchanges?

2- How do the rail operational patterns impact on the rail freight interchange operational requirements?

3- Can the existing simulation modelling tools be used to design rail freight interchanges, considering multi-stakeholders' requirements?

4- How can a simulation modelling tool dedicated to rail freight interchange be developed considering the multiple stakeholders' requirements?

Three case studies for designing and evaluating rail freight interchange layouts considering multiple decision makers are analysed and used to validate the outcome of the thesis.

1.3 Terminology

A variety of definitions for the terms *Yards, Terminals, and Interchanges* have been suggested by previously published studies (Ballis and Abacoumkin1996, Muso 2010, Boysen et al. 2013, Caris et al. 2013, Crainic et al. 2018). To clarify the nomenclature and the precise meaning of the terms, the terminology used in this thesis to describe rail yards, rail freight interchanges and terminals is defined as follows.

For the proposal of this work, “rail yard” or “yard” refers to the rail infrastructure elements used to receive and move the rolling stock within the terminal. Several papers have discussed rail yard types: Petersen, (1977) Betkas et al. (2009), Marinov & Viegas (2011), Boysen et al. (2012).The yards usually can be classified as flat, when the operation is on the same level, or hump yards where the wagons are moved within the yard by the force of gravity. In this type of operation, the locomotive moves the wagons up to a higher point, and the wagons roll down a ramp and are routed through switches to different tracks.

A marshalling yard usually refers to a rail yard and operation processes organised for assembling and disassembling a freight train. In this work, we also use yard terminology to refer to the parts of tracks and switches with a specific operational function. Traditionally, on a marshalling yard, each function is performed in a designated area for example, the most common specific functions of a yard are “receiving freight trains,” where the wagons are received, “storage of wagons,” where the wagons await the train, “classification of freight wagons,” where the wagons are reorganized and subsequently sent to the “departure of freight trains”.

As it can be seen in Figure 1, the yard areas and functions have followed the same concepts for over a century (Droege 1912).

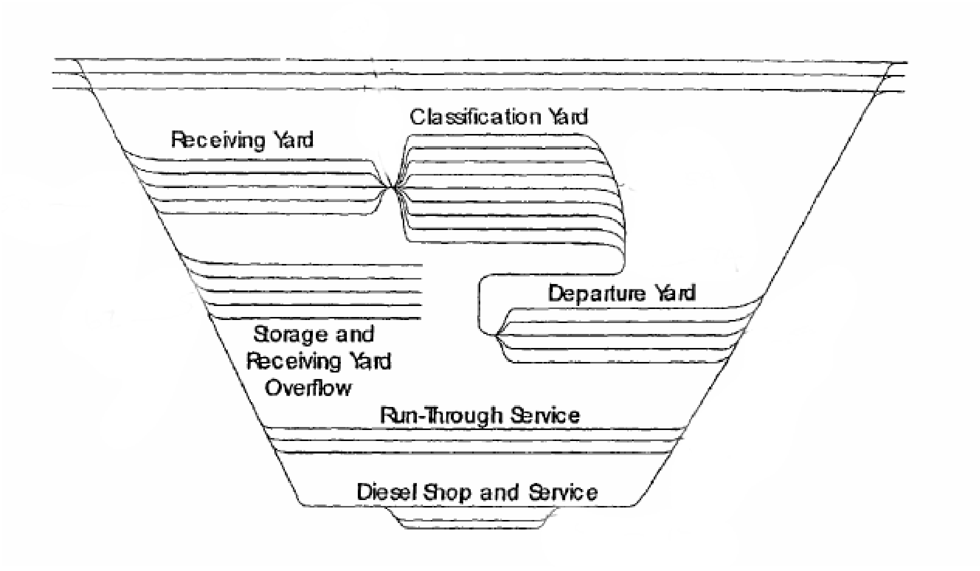

Figure 1 Marshalling Yard/Interchange layout example - Droege (1912)

In general, terminal describes the set of facilities where cargo start and finish their service or are transferred from the vehicles. This includes changes to other transport modes to satisfy user expectations in respect to the quality of service. The “terminal” concept within this work includes all types of rail yards and freight services with all kinds of fixed/crew equipment needed to ensure the rail operation and load/unload terminal operations. Unitary cargo and multiple cargo types of terminals have been developed over the world in reaction to the transport demands.

Since the 1990s, much of literature on rail freight transport paid particular attention to intermodal operation and intermodal issues (Loureiro 1994, Nozick and Morlok 1997, Newman and Yano 2000, Powell and Carvalho 1998, MAcharis and Bontekoning 2004, Bontekoning 2004, Caris et al. 2013, Sakalyns and Batarliene 2017, Crainic et al. 2018). For the proposal of this research, the considerable attention attracted by intermodal terminals research indicates the importance to investigate and discuss the challenges involved specifically with multimodal terminal design. The interchanges concept in this research work follows the definition of the British Government policy for Strategic Rail Freight Interchanges:

> “A Strategic Rail Freight Interchange (SRFI) is a large multi-purpose rail freight interchange and distribution centre linked into both the rail and trunk road system. It has rail-connected warehousing and container handling facilities and may also include manufacturing and processing activities. For many freight movements rail is unable to undertake a full end-to-end journey for the goods concerned. Rail freight interchanges (RFI) enable freight to be transferred between transport modes, to allow rail to be used to best effect to undertake the long-haul primary trunk journey, with other modes (usually road) providing the secondary (final delivery) leg of the journey”

As it can be seen by the definition, the multi-purpose nature of the interchange plays a vital role for the interchange services and layout. Due to the involvement of the different actors (e.g., shippers, infrastructure managers, institutional authorities, customers, rail operators), the complexity of the rail freight interchange goes beyond the traditional rail facilities, requiring lorry receiving lines, parking facilities, storage and other services to support the logistic service (e.g., warehouse, packing, manufacturing, weighing, and quality control).

1.4 The Role of the Rail Freight Interchange in Modern Logistics

Modern logistics are exploring co-modal/intermodal transport concepts to improve the performance of the freight service. Since the 90s, the number of publications in intermodal freight transport research have increased significantly as can it be seen by Figure 2

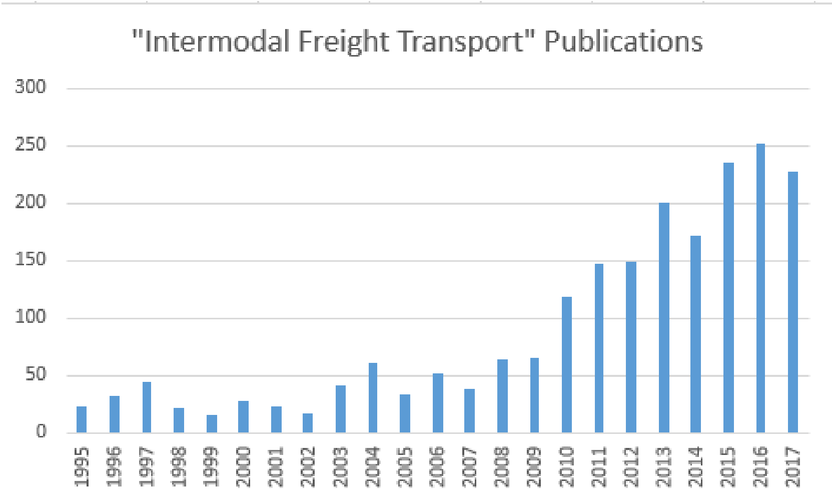

Figure 2: Intermodal Freight transport publications available at science direct

The intermodal /co-modal transport potentially explores the advantages of rail and road. With the rail low energy consumption (and low carbon footprint) for long distances and the road capability for last mile delivery, the intermodal transport can improve the attractiveness of rail freight services.

In this aspect, the interchange is key to improve rail freight performance, the costs of the transhipments, and time spent on the interchanges, which directly impact the overall logistic costs.

Traditionally, the rail freight planning activities are divided in 3 levels, Assad (1980a) Bektas et al. (2009)

- Strategic (long-term) with a duration of 5 to 15 years, involving investment plans
- Tactical (medium-term) with a duration of 1 to 5 years, involving the allocation of resources
- Operational (short-term) with duration between a day and a year.

Although the optimization of operations in interchanges can be defined as short and medium-term activities, new designs for interchanges are a strategic (long-term) activity by their high-cost and influence on the performance of the railway network. According to Bontekoning & Priemus (2004), in Europe, shunting operations may take 10-50% of the total train transit time.

Many authors have analysed the role of the yards in railways. One of the most important references for this work is Assad (1980b), which represents the rail system graphically a network, where the links refer to lines and the interact links are represented by lines in which the trains are moving and the yards as nodes.

Crainic & Lapore (1997) present a mathematical model of the design of a complex network and illustrate it with an example of dynamic service network design. Several other studies with the same approach, involving mathematical modelling in rail yards, have been published in recent years (Wieberneit (2008) Rooda et al (2010) Hu et al (2018)). These works are relevant for this PhD to understand the planning process on the interchange design.

1.5 Evolution of Rail Freight Market

Despite the advantages of rail freight transport, the rail freight market share between 1970 and 1998 fell from 21% to 8.4%, (Epson 2006) leading to policies aiming to reduce the imbalances of transport modes and revert the decline. Since 1992, the European Union has been developing policies and financial incentives to promote environmentally friendly alternatives to road-only freight transport. The White Paper "European Transport Policy for 2010: time to decide" (EC2001) reinforces the need to promote the intermodality in order to improve the environmental performance of the transport system.

> "Unless major new measures are taken by 2010 in the European Union so that the Fifteen [Member States] can use the advantages of each mode of transport more rationally, heavy goods vehicle traffic alone will increase by nearly 50% over its 1998 level. This means that regions and main through routes that are already heavily congested will have to handle even more traffic "
>
> EC 2001

The creation of programmes, like Marco Polo Funding Programme and European Commission, target promoting research and innovation to shift traffic to non-road modes, expecting to expand Rail Freight to 15% market share.

However, analysing the changes in the modal split, no significant progress can be observed towards a modal shift over the last two decades. Figure 3 presents the modal split since 2001, considering the 28 European Union countries.

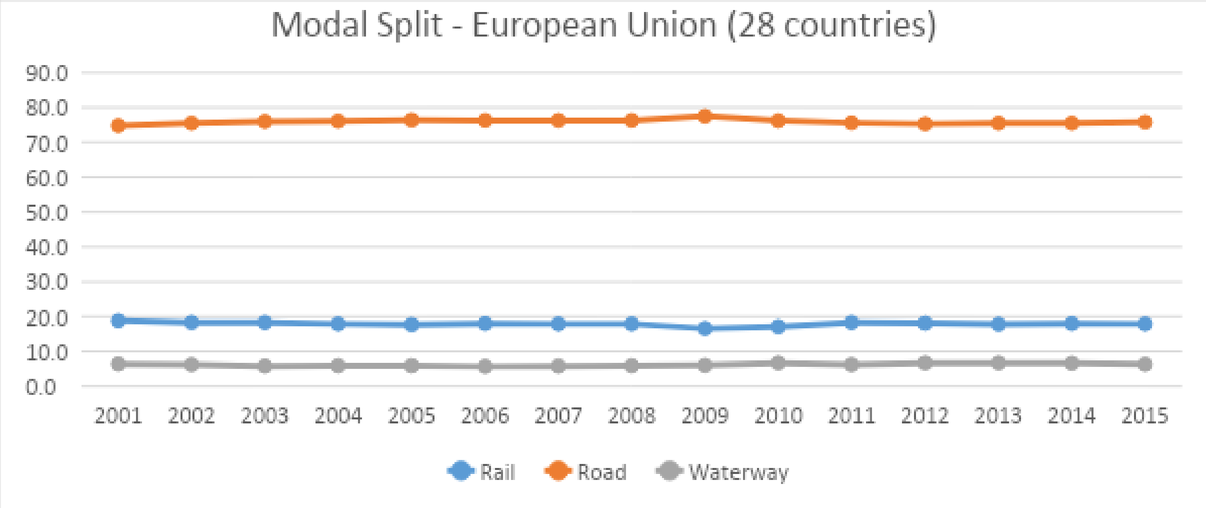

Figure 3: Modal split 28 countries European Union 2001-2015-Eurostat

Surprisingly, with the modal split and the transport growth (Figure 4), the results contradict most forecast and foresight developed in the last decades considering freight transport.

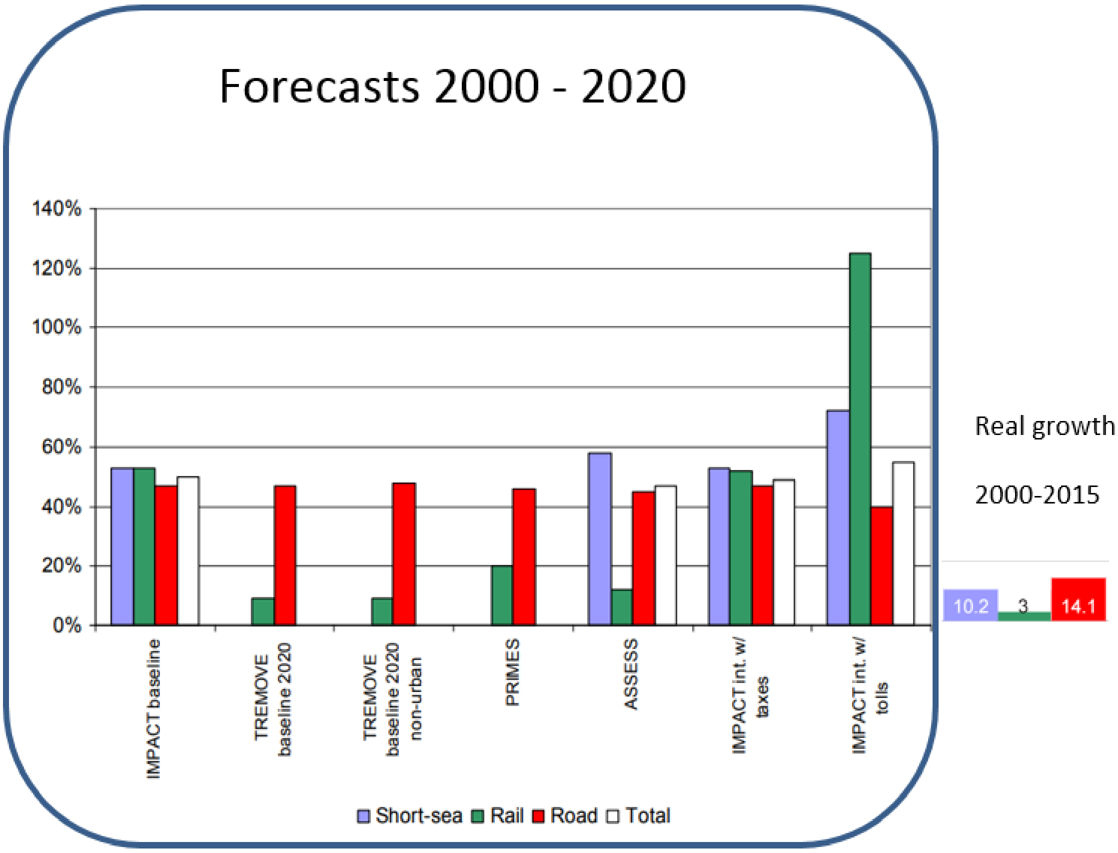

Figure 4: Forecast growth vs real growth (ITREN, Eurostat)

As it can be seen by iTREN2030 forecast models comparative (iTREN2012) overestimate the transport growth, particularly the growth of the rail freight transport, Fig 3. Therefore as the transport demand dramatically impacts on the need for infrastructure, understanding the transport demand potential growth is crucial for the planning process, especially when considering how this growth can impact on the interchange requirements.

The study of rail freight demand forecast within the UK helps to understand the focus of this work in rail freight interchanges. In Freight Market Study (Network Rail 2013), the decline of coal transport and high increase in intermodal was expected (Figure 5).

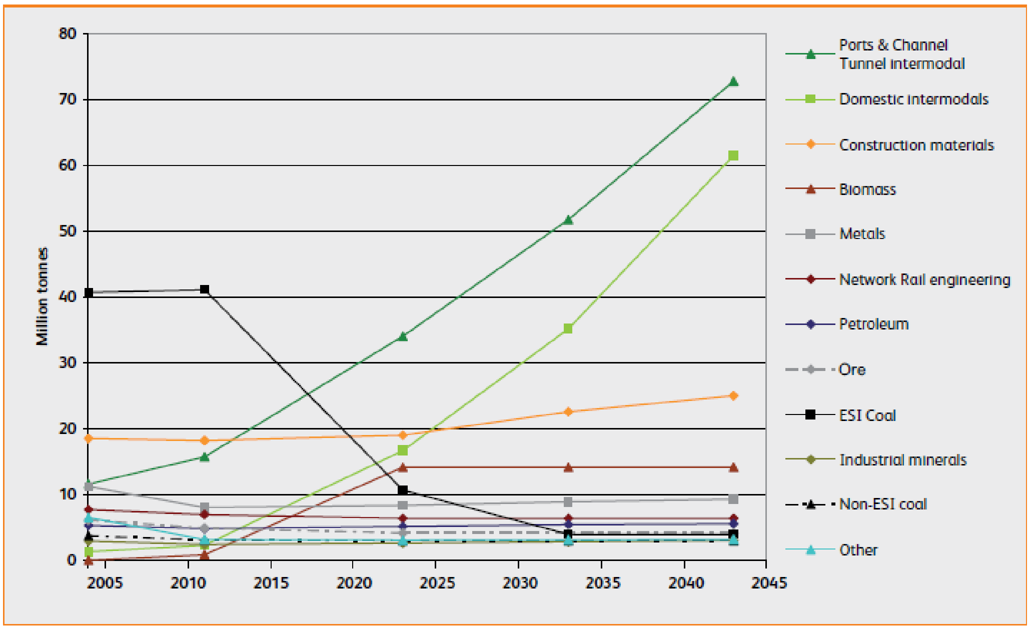

Figure 5: Forecasts by cargo- tonnes lifted (Network Rail 2013)

However, the changes in the rail freight market happened faster than expected (Figure 6), resulting in a significant need for terminals to handle new cargo (e.g., biomass, intermodal traffic), and at same time, coal terminals closed. This event suggests a need to understand the key constraints to the effective movement of this new freight in railways. Moreover, it is necessary to learn how the demand for freight might change over the next 20-30 years and how new technology potentially could increase the efficiency and productivity of rail freight.

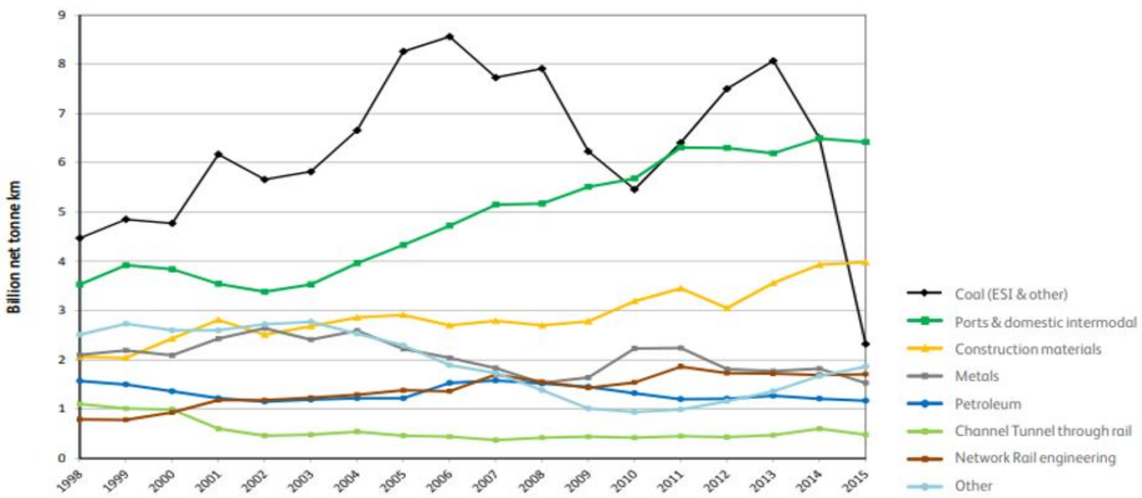

Figure 6: Real growth- Cargo type

An efficient and attractive rail network can optimise the connections between congested city centres, providing efficient logistics. With the increasing growth of intermodal flows, the role of rail freight interchange will become more significant and will involve new stakeholders (e.g., terminal operator, society, logistic operators). Therefore, there is a clear need for more efficient interchanges, increasing the railway participation in the freight market and reshaping outdated/low demand infrastructure to satisfy requirements of new stakeholders in this new market, improving the connections between rail and road.

1.6 A Methodological Approach for designing Rail Freight Interchange

A comprehensive review of the terminal technology, performance evolution and rail simulation modelling tools was undertaken to understand how to develop software applications to model multiple stakeholder’s priorities. New software package applications for designing rail freight interchanges were developed, which simulate the impact of multiple infrastructure and equipment for multiple stakeholders (e.g., public authorities, freight operators, consumers, infrastructure operators). The decision support tool enables easy physical design and performance evaluation of a new rail freight interchange.

Despite the importance of a multi-stakeholder’s analysis of infrastructure design, a few studies have used multi-stakeholder approaches to model multi-dimensional problems. The incorporation of multi decision drivers in the software application is useful for infrastructure managers, policy makers, and railway operators in the decision-making process for strategic and tactic planning relating, for example, for interchanges and terminal design or to redesign an existing terminal to meet new transport demands.

Innovative visualisation tools, based on 3D navigation and virtual reality, developed as result of this thesis aim to enable the user to visualise the terminal design to identify possible constraints.

The scenarios generation tool aims to develop different technical parameters of the freight interchanges under different priorities to evaluate how a specific design met current and future transport demand for different stakeholders.

1.7 Scientific Contribution

The research work explores the operational characteristics of rail/non-rail elements of rail freight interchanges (e.g. cost, energy consumption, performance) to understand the interrelation between the elements (operations and infrastructure). The scientific contribution of this thesis includes:

- An understanding of the complexity of the multi-stakeholder analysis approach, analysing stakeholders directly or indirectly involved in the interchange decision to create a multi criteria performance evaluation tool;
- An artificial intelligence (AI) tool to support decision making for rail freight interchanges based on user priorities, the development of software package using innovative metaheuristic based on genetic algorithm (GA) ;
- A multi scenarios generation tool to model evolving scenarios to enable dynamic measures of performance for different decision drivers on interchange design; and
- A virtual navigation tool based on 3D navigation to enable the decision maker to visualise interchange/ terminal layouts.

1.8 Thesis Organisation

This thesis reviews the existing state of the art in rail freight operation and infrastructure in Chapter 2 to understand how the operational patterns and infrastructure impact on the rail freight interchanges requirements. The state of the art and the state of the practice of rail freight simulation modelling are discussed in Chapter 3 to understand how the existing software simulates and evaluates the rail freight system. Chapter 4 presents the methods used in the development of the software packages framework based on Technology Roadmapping, describing the integration of Multi stakeholder Decision making methodologies, Analytic Hierarchy Process and Genetic Algorithms for creating a rail freight interchange supporting decision tool. The proposed framework aims to identify and combine the main strengths of the above methods in order to support the development of multi stakeholder simulation tools. With the inputs obtained from Chapter 2, 3 and 4, the implementation of the software's packages is presented in Chapter 5 (Figure 7). Three case studies of modelled applications are presented in Chapter 6 to illustrate the implementation of the software package developed. Chapter 7 concludes the thesis and discusses further research and developments.

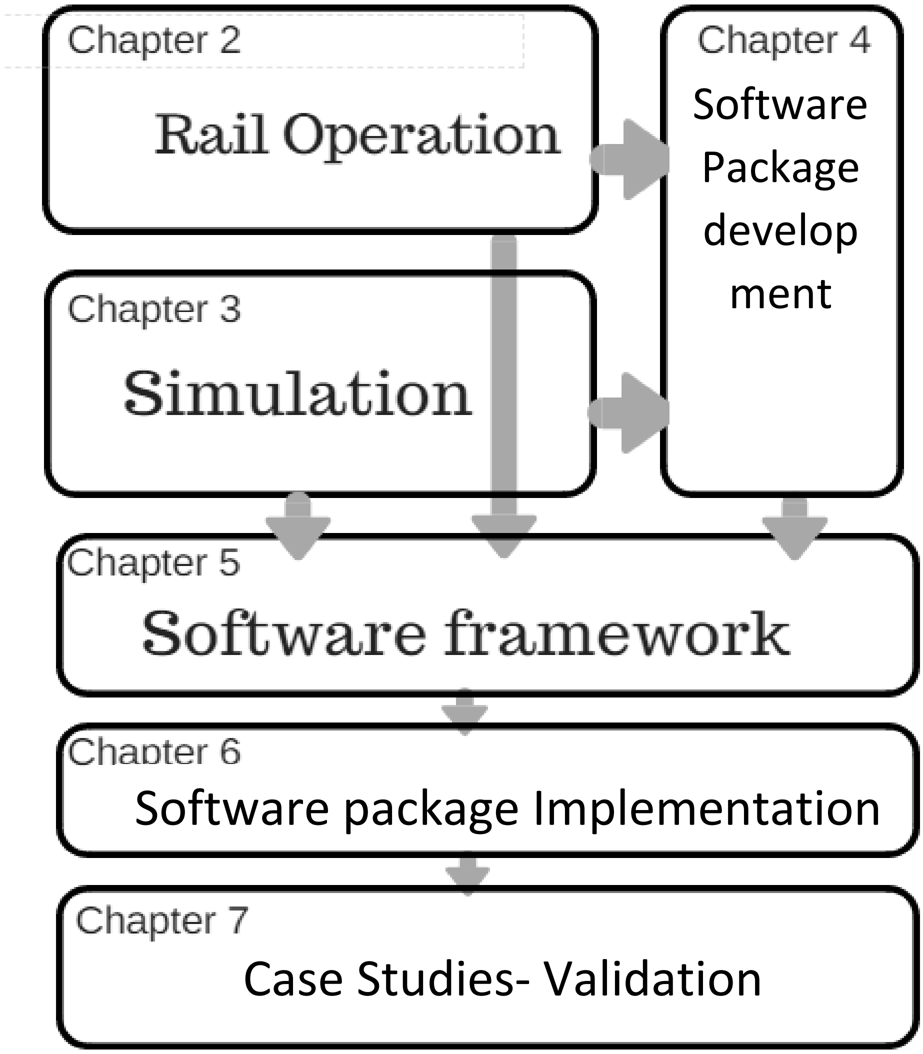

Figure 7 : Thesis organization

Chapter 2: Rail Operations, Yards and Interchanges

Rail transport has a multi-disciplinary nature, encompassing engineering and business. Although a holistic approach to the rail freight transport field is taken, this research work focuses on rail freight interchanges from an industrial and mechanical engineering perspective. This chapter focuses on the state of practice in rail operation, introducing the concepts and definitions of intermodality, rail yards and interchanges in order to investigate the main technical characteristics of operational modes and to study how these facilities are planned. The types of infrastructure and main equipment and technology for railway yards, intermodal transport, and interchanges are presented. The main research question proposed in this chapter is: "How do terminal/interchange elements and operation patterns impact the Rail Freight Interchanges ?"

2.1 Introduction

Intermodal transport is the way to combine the advantages of different transport modes. Using the conjunction of different modes, rail can improve cost competitiveness, quality of freight transport and offer a more flexible, reliable, profitable, and environmentally friendly freight transport service.

However, to deliver these benefits, intermodal transport requires cost-efficient terminal operations to enable efficient last mile delivery and allow increase of the rail market share. The combined costs, rail/road, and transhipment operations need to offer as a competitive advantage for the hauliers in comparison with road transport. As the interface between road and rail, the intermodal freight terminals/ interchanges are a key element in the integrated supply chain logistics.

2.2 Rail Freight Operations, Infrastructure and Transhipment

For the interchange operations model three pillars were considered (Figure 8). Transport operations, denoting the operational patters and describing how the rail freight is sorted and organized (operating forms). Transport infrastructure denotes permanent facilities that enable freight movement, e.g., lines, siding signalling, vehicles, parking area for road vehicles. Transfers are an interchange element focused on cargo handling, e.g., transhipment equipment, cargo sorting, logistic service buildings and warehouse.

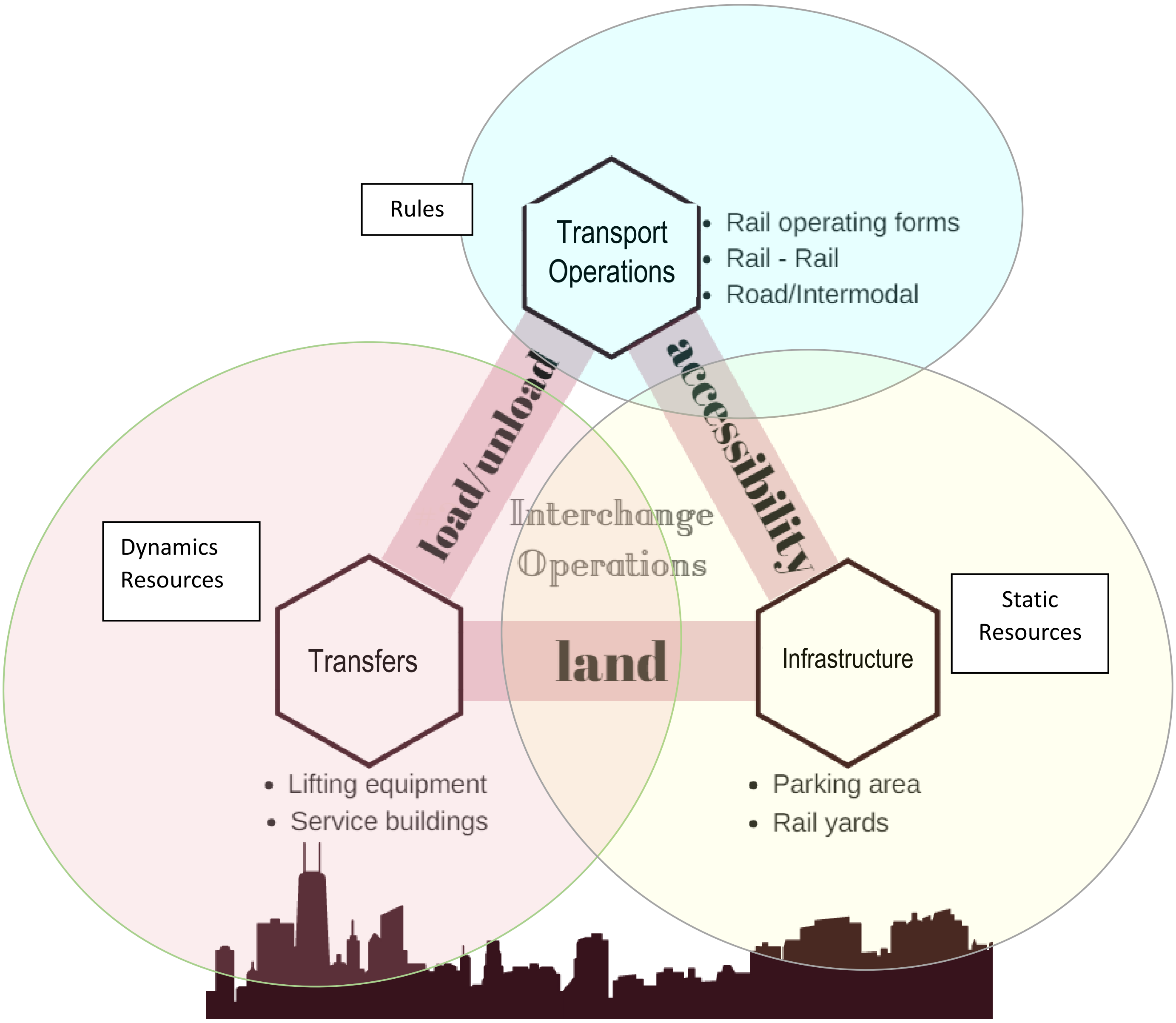

Figure 8: *Three pillars for interchange designing*

Traditionally, in rail operation, the vehicle choice is limited by the nature of the cargo and energy source available. Generally, freight trains utilize diesel-electric traction requiring fuelling facilities. Therefore, based on the rolling stock available and client requirements, the service infrastructure need to be flexible. In principle, the framework proposed in this research work for design of infrastructure, considering multi-objective optimization, can be adapted for other transport modes and for different flows (e.g., airports, ports, and passenger trains), nevertheless the focus here is limited to rail freight.

2.2.1 Facilities and Lifting Technology

In order to create the interchange modelling framework, the accessories and buildings not immediately involved in the rail operation are grouped as facilities.

The straddle carrier is an individual container elevation system that is engine, diesel or electric powered (Figure 1Figure 9). Capable of stacking 2 containers and raising the 3rd container to pass over two-high containers. Straddle carrier is generally utilized for serving 20ft, 40ft, and 45ft ISO containers.

Figure 9: Straddle carrier (photo creative commons)

Figure 10: Container forklift (Photo by Alfvan Beem)

Forklifts (Figure 10) and Reach stackers (Figure 11) tend to be typically utilised for handling containers in compact terminals or moderate-size ports. Forklifts and Reach stackers move the container rapidly in small ranges and are capable of piling them in various rows. The mobility and higher stacking and storage capability gives a competitive advantage when compared to Straddle.

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Figure 11: Reach stacker (Photo by Kalmar Peinemann)

Rubber Tyre Gantry Cranes (RTG) are widely utilized in container yards, ports, and workshops to load and unload, not exclusively containers but also general cargo on different vehicles (Figure 12).

Figure 12: Rubber Tyre Gantry Crante (photo creative commons)

Rail mounted gantry cranes (RMG) are largely used on intermodal operations. The weight is supported from a beam and well-allocated using an intricate system of wires and attachments to support the weight of the cargo.

Ferreira and Sigut (1993) provide helpful comparison costs associated with the lifting products presented in Table 1: Type of transhipment equipment characteristics.

Table 1: Type of transhipment equipment characteristics

Type of equipment	Span(m)	Capital cost ($AM)	Expected life (years)
Rail mounted gantry	9-35	1-3	12-25
Rubber Tyre gantry (wide)	20-25	2-2.5	12-20
Rubber Tyre gantry (narrow)	9-13	0.8-1.5	12-20
Reach stacker	--	0.8-0.9	8-12
Staddler carrier	1 container	0.7-1.1	8-12
Forklift	--	0.5-0.7	8-12

Comparable work provided by Moghadam and Noori (2001) has reviewed the evolution of the expenses for semi-automated Straddle Carrier (SC), Rubber Tyred Gantry (RTG), and automated Rail Mounted Gantry (RMG) container yard operating cranes (presented in table 2).

Table 2: Standard purchase cost of container yard lifting system, £/equipment

Year	SC			RTG				RMG			
				5+1		6+1		11+2		12+2	
	1 over 2	1 over 3	1 over 4	1 over 4	1 over 5	1 over 4	1 over 5	1 over 4	1 over 5	1 over 4	1 over 5
1990-1994	175.300	190.550	-	217.250	228.570	230.350	247.500	522.320	566.320	587.140	604.450
1995-1999	191.750	213.310	-	321.200	330.240	385.870	407.760	612.550	633.540	609.240	614.250
2000-2004	232.450	260.870	290.780	394.200	419.150	440.400	471.550	640.100	667.140	610.320	623.200

As it can be seen in Table 2, in the first half of the 90s, the costs of RTG are slightly higher than Straddle Carriers; however, the thee costs of the RTG system have grown significantly over two decades (85%), while the RMC system costs increased around 15%. The decision regarding the handling system illustrates the need to consider the available technology and their costs.

2.2.2 Rail Freight Operations

To understand how rail facilities impact and are impacted by the operation, a review of the rail operations is further described in the next section (Figure 13).

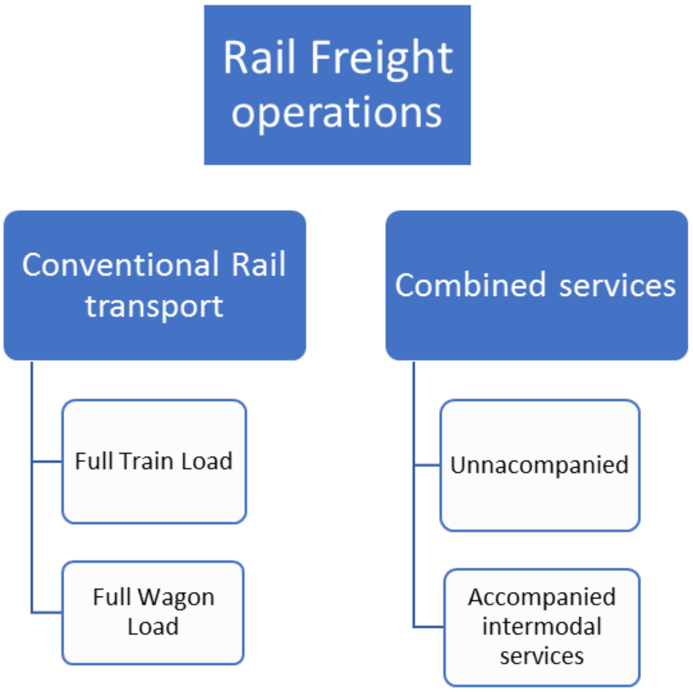

Figure 13: Rail freight operation services

Full train load describes any consignment comprising a train with several wagon loads transported together for one consignor with no change in train composition from single point of loading to single point of unloading.

Full wagon load (single wagonload) describes any consignment of goods requiring the exclusive use of a wagon throughout its journey, whether the full wagon loading capacity is utilized or not. The term block train is generally used as synonym of full train load or just trainload. This type of rail supply is operated when a single client does not have enough quantity to load a full train.

Single Wagon Load service requires the availability of a specific infrastructure to operate. Shunting or marshalling yards are required to assemble / disassemble the wagons according to their destinations. Port terminals often comprise private sidings, operation yards, and intermodal terminals.

Over the last decades, the SWL has declined from 40 to 33% of rail freight. According to Single Wagonload Traffic in Europe study (EC 2015), in the United Kingdom, almost all infrastructure used for SWL traffic have been dismantled; a UK statement given by the rail Infrastructure Manager explains:

> *"Freight services on the GB railway network generally run as block trains direct from origin to destination without the need for intermediate marshalling with other wagons. Some freight train operating companies operate a small number of yards where their pattern of trunk and feeder service requires trains to be re-marshalled".*

The way the rail freight is sorted and organized in different operating form is also affected by the transport demand and commercial requirements, impacting directly on the layout needed. Ballis & Golias (2004) identified four commons patterns of operations in rail yards Figure 14shows the operation with direct trains between two points.

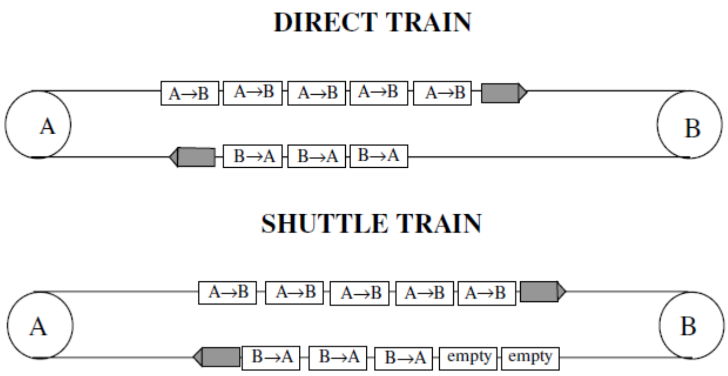

Figure 14: Schematic diagram of direct and shuttle train operations - Ballis & Golias (2004)

In shuttle train operation, the same rolling stock goes from A to B and returns to A without the need for decoupling all wagons. This type of operation is faster, quicker, and more economic. The yards specifically for this type of procedure are simple and depend on the demand for transport. It is often operated with a limited number of auxiliary sidings. Figure 15shows operation by groups or feeder system.

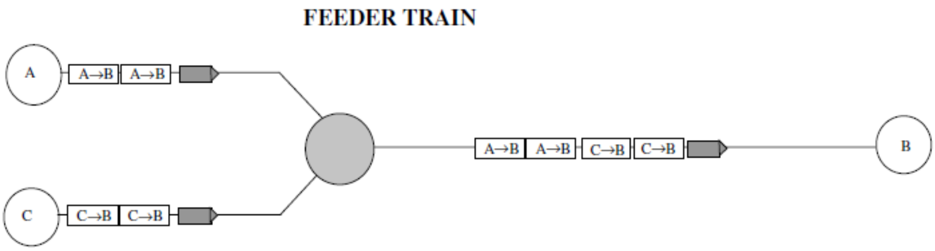

Figure 15: Schematic diagram of feeder train operations- Ballis & Golias (2004)

In this type of operation, the trains originating at station A and C are marshalled together before the complete train is driven to B. These systems are widely used in logistics systems where loads have various origins and a unique destination, traditionally a port or intermodal terminal.

Interchanges of this type usually have several auxiliary lines in the terminal marked with the arrow. In this type of operation, the wagons can be stored in these lines while waiting for the train to follow to its final destination.

Similar to a feeder operation, it is linear through trains as shown in Figure 16.

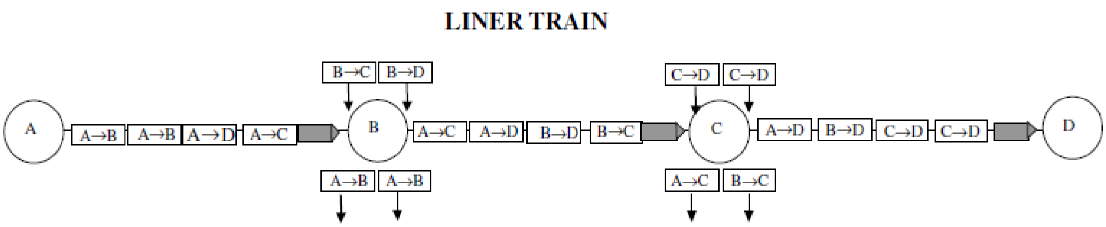

Figure 16: Schematic diagram of liner train operations -Ballis & Golias (2004)

This model differs from the previous one, as there are multiple destinations on a single line. This type of operation demands larger yards to enable decoupling and recoupling of wagons, depending on their desired destination, and a place for storage of wagons awaiting the arrival of a train. The HUB operating formFigure 17 () is the most complex and most widely studied.

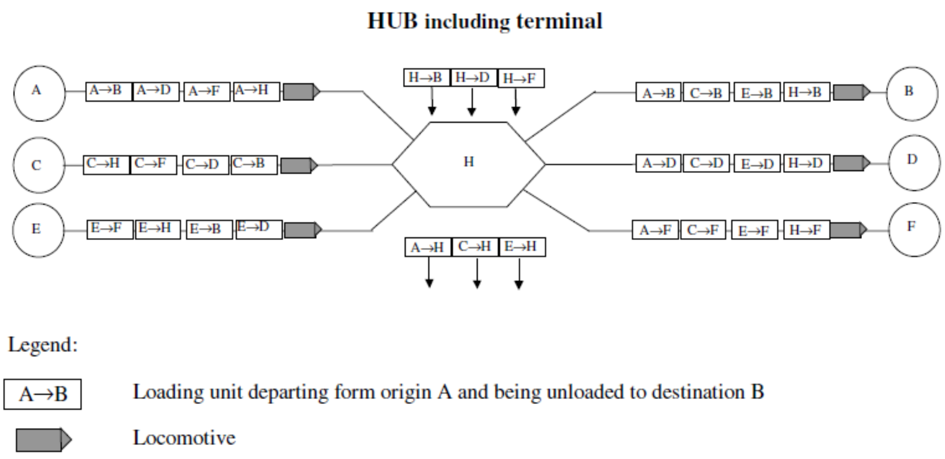

Figure 17: Schematic diagram of HUB terminal operation -Ballis & Golias (2004)

Operations of this type involve interconnection of trains with different origins and destinations. The trains are rearranged at the yards, and this operation usually requires several lines for storage of wagons, since different trains arrive at different time intervals.

Woxenius (2007) suggested six transport operation network designs and characteristics (Figure 18). Each design possesses operational qualities and matches different conditions (geography, demography, infrastructure and transport demand).

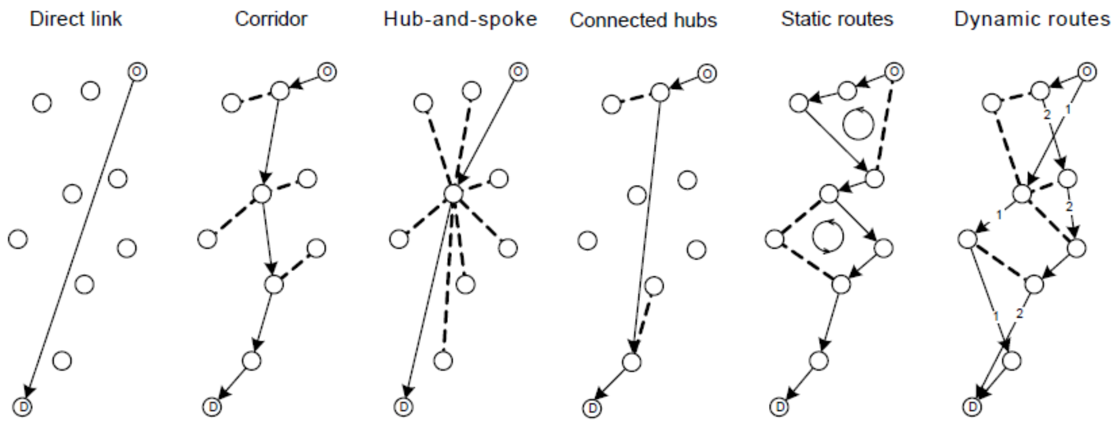

Figure 18: Schematic diagram of the six transport operation network- Woxenius (2007)

In a Direct link operation, the train locomotive runs directly between an origin and a destination. Direct links are the most efficient operating form in rail operator perspective but could demand sufficiently large flow.

In Corridor operation, the train passes through intermediary terminals before the final destination. This operation pattern commonly offers regular service and high frequency, enabling the consolidation of larger terminals with more compact terminals/demands in a network

The hub-and-spoke operation is characterized by the freight movement of the central node (Hub) for the loading and transhipment process. In this network layout, in most cases, it is possible to offer a large number of connections between origins/destinations with medium /smaller terminals. This operation could require extensive marshalling yards for train formation, operations that could result in long waiting and train formation times. Transhipment technology are vital to supply fast cargo liftings between different trains, as a failure or delay would paralyze the whole network.

The connected hubs design is a hierarchical model in which the local flows are collected at terminals connected to alternative terminals. The static routes design can be characterized by the number of links to be utilized on a routine basis by the transport operator. In this operational pattern, several nodes are used as transfer connections along the route. Not all nodes provide transhipment or load services.

Dynamic route layout provides the greatest flexibility. The links are designated according to existing demand, and the network operator can choose different paths for origin and destination. Transport services can be organized by optimization methods or heuristics. Understanding the differences among the rail operational patterns and the interchange design concepts with their operational conditions one could identify techniques to support the cargo shift from road to more energy efficient transport modes.

To improve the overall performance of rail to absorb a significant share of freight flows innovative solutions should be developed to reduce the life-cycle costs of the infrastructure assets and to target future interoperability requirements, including improvements in security/ safety, reliability, and maintainability.

To understand the effect of lifting expenses on the overall performance of intermodal transport, Behrends and Floden (2012) analysed the use of ground-breaking transhipment technology for fast and efficient liftings and relationship with terminal costs.

Although advanced innovative terminal concepts have been proposed by industry, they have not been deployed. This view is supported by Bontekoning et al. (2004) following a study of 92 publications over intermodal logistics, stating the role of the terminal in the intermodal freight transport and claiming that, recently, several types of research are coming through in this subject.

In his analysis of Bundling process, Kreutzberger [2004] attracts our awareness in that, in complex bundling, modest flows also could experience advantages of large-scale operations. As it can be seen in Figure 19, the bundling potentially affects the quantities, sizes, and models of the terminals on the network. Understanding the bundling type, which has the best equilibrium between benefits and disadvantages in relation to operational, generalized, or social costs, the network manager is able to generate the operational strategy.

For the operational strategy, Kreutzberger (2004) distinguishes five bundling network models (direct network, hub-and-spoke network, line network, fork network, and the trunk-feeder network). The results suggest a correlation between regularity, transport volume, and efficiency of the network types.

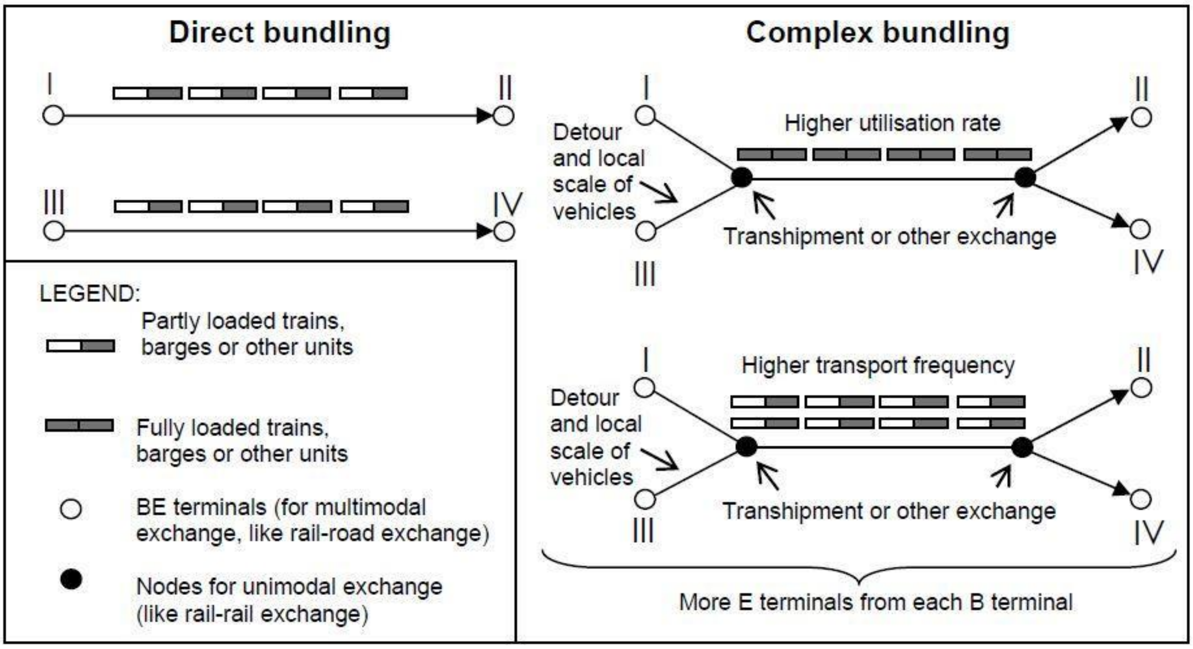

Figure 19: : Schematic diagram of bundling Network showing the operating forms and transhipment activity

Looking at the multiple nature of the stakeholders concerned in the terminal decision process and the need for new measures to make hinterlands transport more sustainable, Bergqvist et al. (2010) proposed Multi-Actor Multi-Criteria Analysis to evaluate hinterland logistics. The methodological analysis considers the assessment of criteria appropriately planned by different stakeholders. The investigations suggest the handling expenses and road transport play the biggest role in the choice of alternatives.

GIFTS project (EC 2012) developed a web platform of services contemplating numerous stakeholders (Transport Operators, Consignors/Consignees, Authorities and Financial Services Operators) and proposes well-equipped vehicles to control distinctive activities.

2. 3 Rail Infrastructure

2.3.1 Switches:

The switches are a key feature in railway operation and are one vital component in yards. The switches are responsible for changing the train path providing guidance to the train (Figure 20).

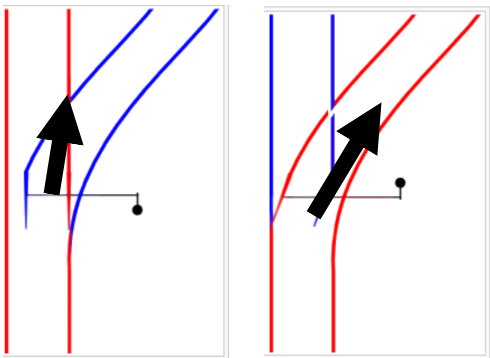

Figure 20: Changes on switches and the respective train paths

Depending on the terminal layout, various systems of switches can be used Figure 21illustrates some classic layouts.

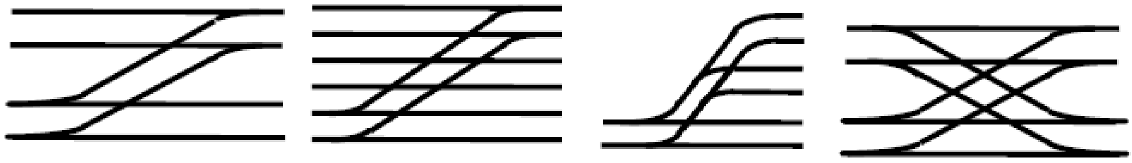

Figure 21; Classic switches layouts such as escape, diagonal , haz and bretelle (ADIF 2008)

2.3.2 Signalling System

Devices are used to transfer information along the track, stations, and trains. These messages can be through the sounds, colours, and shapes (Figure 22). Significant transformations in switches and signalling systems resulted from the technical improvement of recent decades.

Figure 22:Signalling system examples such as semaphore (shape and colour) and ERTMS (ADIF2008)

2.3.3 Rail yards

Yards are different parts of the interchange with specific roles. Within the context of shunting/marshalling yards, the most common are receiving yards in which the wagons are received and classification yards where the rolling stock are reorganized into departure yards.

Based on the regional topology available, the transport demand, and the costs, a variety of designs for marshalling yards or interchanges could be adopted. Figure 23 shows different layout options.

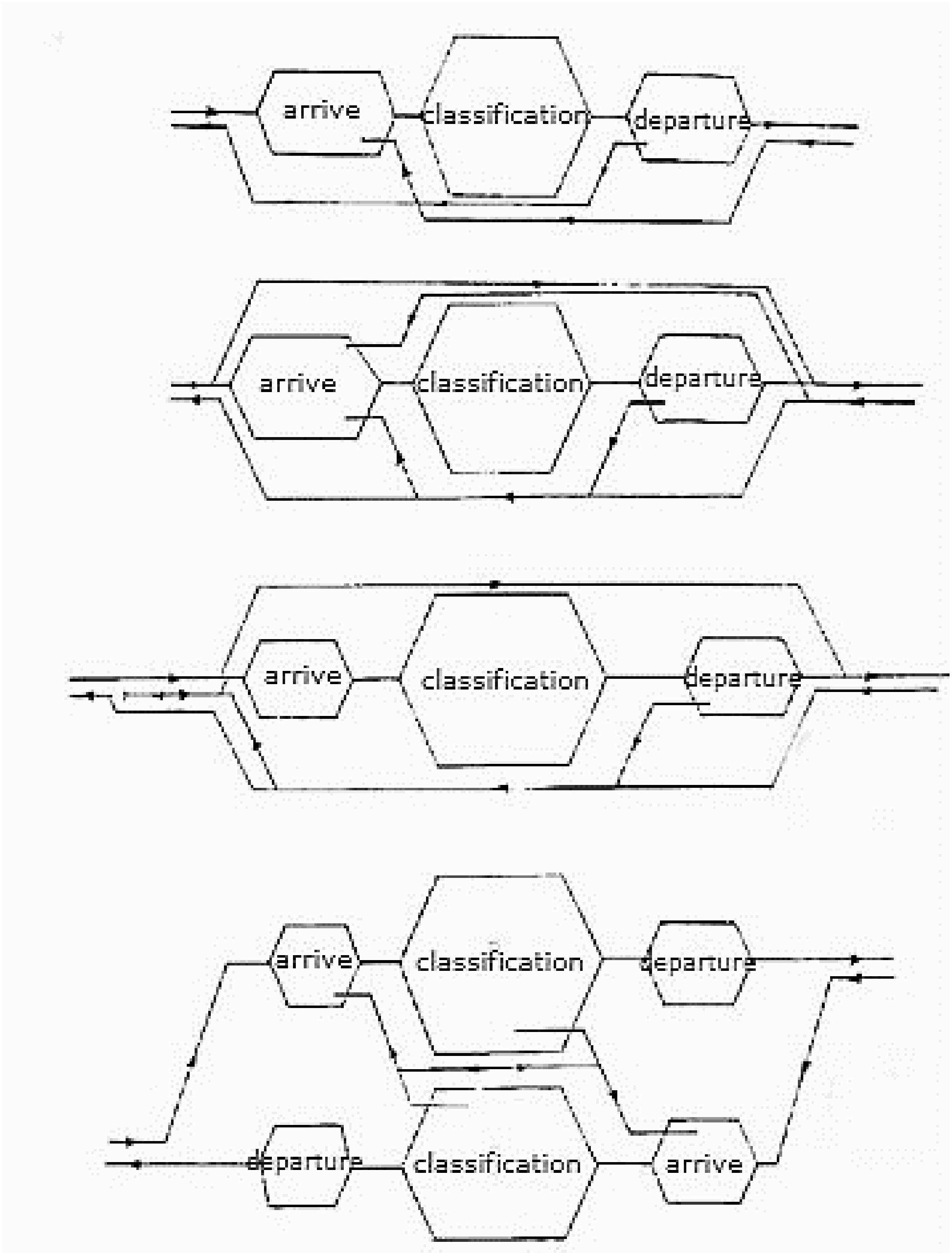

Figure 23: Typical rail yards layouts adopted depending on the transport demand and terrain topology

In recent years, railway providers have experienced a significant decrease in yard utilization. Therefore, several shunting and marshalling yards in Europe operate under 15% of their functional capacity due to the decrease in the flows of some traditional "captive" commodities.

2.3.4 Rail Freight Interchanges

The UK Strategic rail freight interchange policy guidance considers the interchanges as strategic infrastructure and long-term investments to enable industrial growth and development of a cost-effective logistic. To be appealing and effective, rail service substitution and development of the interchange facilities could be required to formulate the conventional rail markets and for the opportunities where the railway has little presence.

The UK Department for Transport (DfT) published in 2011 a guidance for Strategic Rail Freight Interchange SRFI (Dft 2011), paying attention to the importance of planning logistics for the SRFIs. In march 2018 the policy guidance has been superseded by the National network national policy statement (Dft 2014). According wuth the policy guidance the SRFIs requires more than 60 hectares and must be capable of handling over 4 trains/ day and provide a number of rail-connected facilities to create a comprehensive rail link in the long-term.

For the performance of complex transport networks, the interchanges on the potential future market scores are exactly where the conventional terminal commonly fails to meet all performance specifications:

- Speed/capacity required by the client
- Appropriate layout for fast handling
- Handling Technology for high-performance transshipment (speed/cost)
- Internal wagon movement to effective operation.

This new generation of terminal concepts demands, not only the technical aspect, but also financial feasibleness for the railway network. With this aspect, the innovative interchanges concepts might involve intelligent system, compact design and synergetic operations for storage, transshipment, and internal movement. The technology and the role of the interchange need to satisfy the client requirement.

Investigations on new-generation terminals (TERMINET 2000) recommend new network and terminal layouts, depending on expense and performance analyses. By contrasting of alternative terminal layouts, 5 terminals: Metz, Valburg, Busto, Duisburg, and Venlo, have distinguished movements to highly automated/ automatic, with integrated operations and compressed design. Table 3 shows the impact of variables on the potential application of new generation operation.

Table 3: Variables and their impact on new terminals

Explaining variable	Metz	Valburg	Busto	Duisburg	Venlo
Perception of innovation					
Relative advantage a)Performance/Service	++/n.a.	+/-	+/n.a.	+/n.a.	+/n.a.
b)Costs	+/-	-	+	-	n.a.
Compatibility	--	--	-	+/-	--
Complexity	-	-	+/-	+	-
Triability	+/-	+/-	+/-	+/-	+/-
Observability	+	+	+	+	+
Uncertainty	n.a.	-	n.a.	n.a.	n.a.
Potential adopter					
Size	+	n.a.	+	-	n.a.
Degree of specialization	+	n.a.	+	n.a.	n.a.
Type of decision	n.a.	n.a.	n.a.	n.a.	n.a.
Information, communication and social system					
Availability	+	+	+	+/-	+
Quality	-	-	-	+	-
Value	n.a.	+/-	n.a.	n.a.	n.a.
Social System	+/-	-	+	+/-	+/-
Degree of competitiveness	+	++	++	++	++
Innovator supplier					
Marketing strategy	++	-	n.a.	-	+
Government					
Active outreach programs	-	-	-	-	
Subsiding R&D/ increasing information/ reliable information	+	+	+	n.a.	+
++ Strong positive relation to implementation + normal positive effect +/- diffuse effect (both positive and negative) - negative relation with implementation - - very negative relation					

As can be observed, by the distinctive criteria, the terminal options have been formulated contemplating a variety of criteria of the stakeholders engaged. The terminal/interchange design must consider the complexity of the trade-offs in the railway operation.

In Ballis and Golias (2002) research on the technical and logistics advancements of rail–road transport terminals, the costs play a significant role in the design process. They have recognized several costs compared to volume curves for various terminal configurations (Figure 24). These curves illustrate the impact of the decision on the operational lifting equipment required. For high transport demand, the lifting costs decrease due to the economy of scale. Reach Stacker machines are (curves 1, 2 a) mostly used on lower demand terminals.

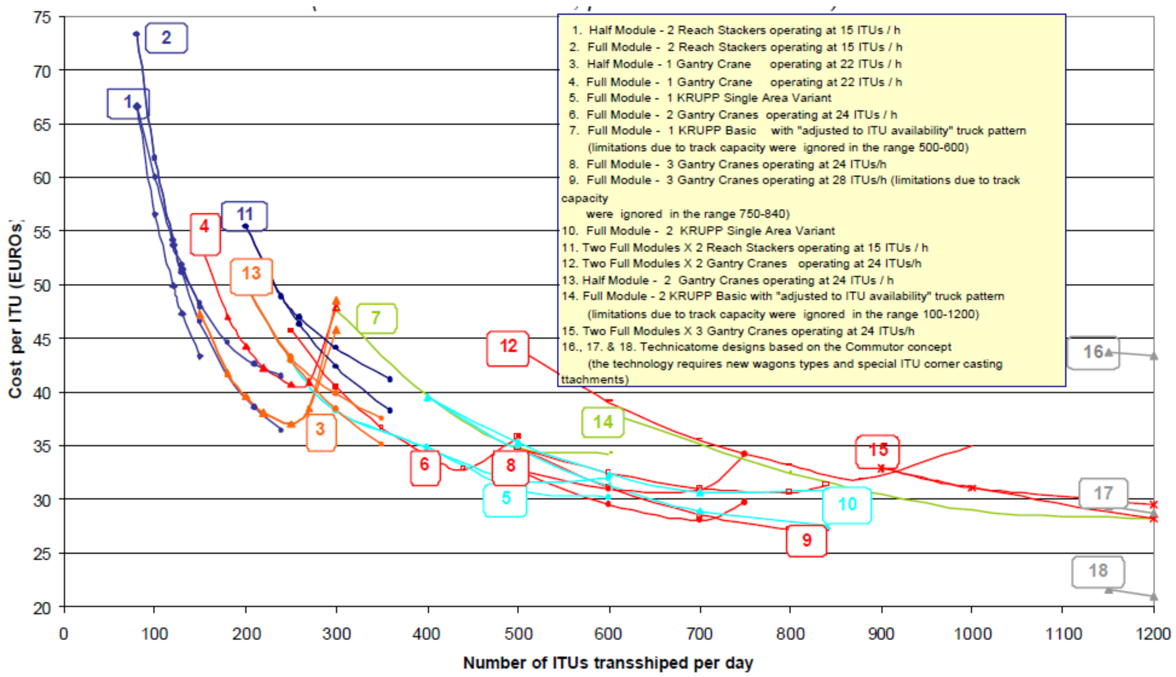

Figure 24: Comparative cost analysis for alternative terminal designs (includes infrastructure, personnel and truck times) (Ballis & Golias 2002)

Figure 25 illustrates (IMPULSE-2000) an evolution of terminal operations using fully automatic operation. The freight is checked by electronic sensors in the preliminary zone, amended where necessary, and the appropriate instructions scheduled for the equipment located further down the line. In the layout presented in Figure 25, an example of a cross-section of rail–road terminal is equipped with three gantry cranes.

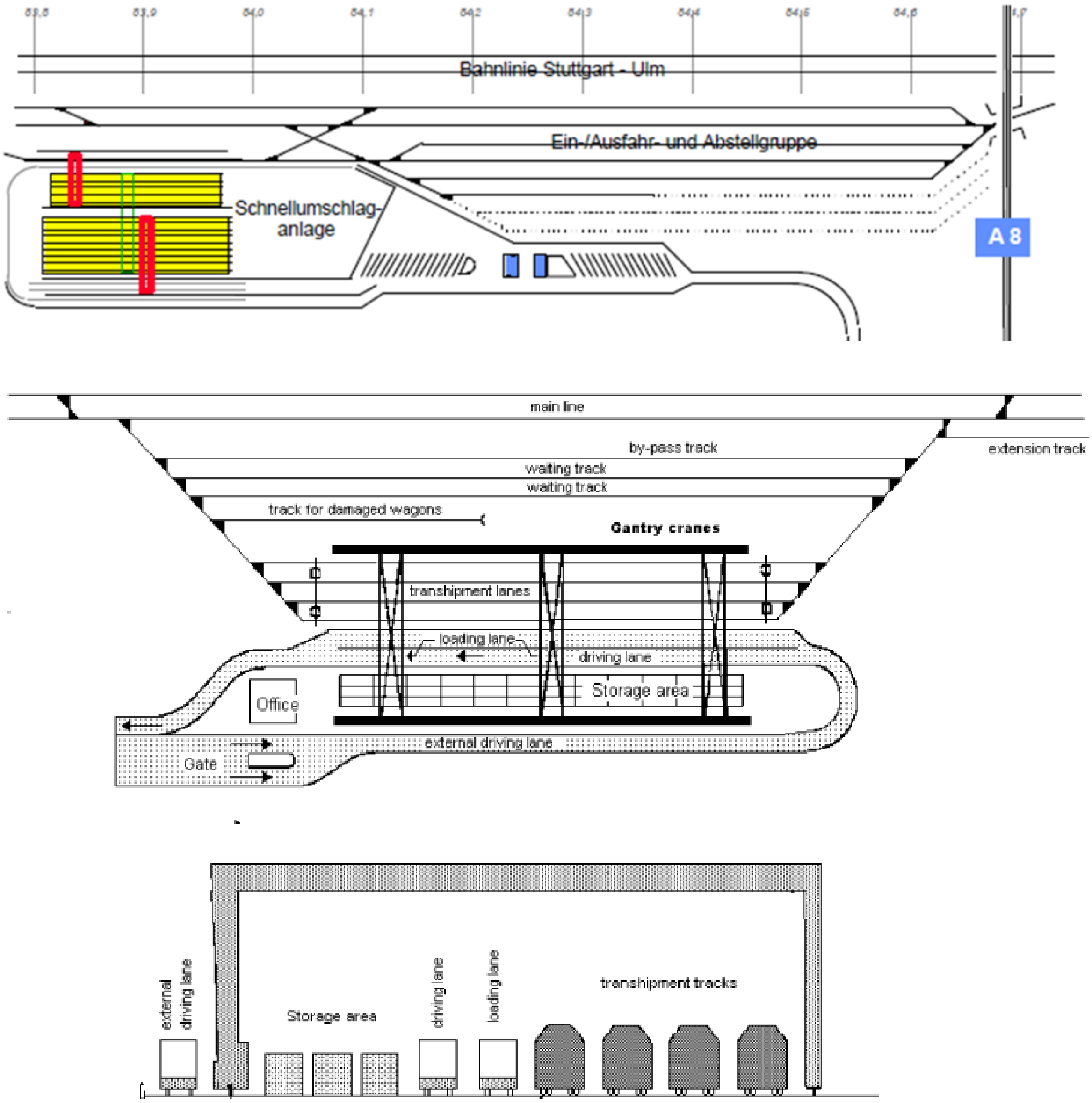

Figure 25: Layout of Krupp Fast Handling System showing the terminal wagon sorting and organization (Impulse EC 2000)

The growth of rail freight in the future market requires a considerable increase in investment in rail connection and implementation of technology. Enhancing the intermodal handling capacity enables the rail to serve the major centres of economic activity. However, the design of the interchanges and the lifting machinery used needs to be upgraded to support the increase in cargo flows.

2.3.4 Rail Freight Transport Planning

Railway infrastructure layout issues and strategies have been extensively examined by railway researchers. One of the first works investigating the complications of the rail yards layout was introduced by Droege (1912) to examine the basic specifications of the terminal design, utilizing track development cost analysis and maintenance details.

The main focus regarded the cost of these facilities. Figure 26 shows an example of an infrastructure recommendation for areas where the yard design with the terminal on the double track in both directions is not possible. With the "lap principle," the construction operating costs could be decreased and enhance the operational capacity. The layouts and models depend on demand functions and costs to optimize the infrastructure.

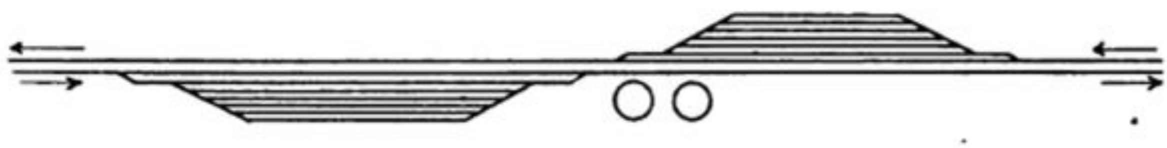

Figure 26: Main tracks through center terminal yard on "lap" principle (Droege 1912)

By the 70's and 80's, several researches applied optimization and computer simulation models addressing railway issues. Assad (1980) categorizes the main rail models released in that period in accordance to the category of those models. Optimization approach with queuing models and simulation models for planning activity, with emphasis on railway yards, has been utilized to explore the railway guidelines and main yard activities. The cost impact of the yard and delay impact by movement patterns on the yards potentially affect the whole rail network. Yard design and the yard costs function described by Assad include:

- Inspection and classification costs- Operational resources used in inspecting and breaking up of the incoming trains. Include yard equipment (yard-engine-hours) and labour means (inspection crews).
- Yard delay costs-Associate time costs to the complete delay and how queueing should determine the network and waiting times.

In the context of the planning yard and link, the capacity at the strategic level is studied, looking at a possible adjustment in link structure and potential expansions on rail yards. Tactical level traffic demands (OD requirements) are used to measure network effects on yard policies, in special blocking techniques. The changes for the international market for freights and crescent uses blocking techniques (a number of wagons grouped toghether) for modern railways which makes the Asad analysis (Asad 1980a) an important reference. However, the severe barriers to effective implementation of the models indicated by Asad, input specifications with reliable costs information and complexity for computing high traffic, indicates a different technique or metaheuristic approach might be needed to analyze complicated yard layout challenges.

In a case study concerning North American yard reconstruction planning, Elliott et al. (1980) explores 4 alternatives for developing the operation to improve the yard capacity and performance by extending 21 classification tracks to maintain 40-50 wagons, introducing two departure yard tracks and developing two parallel pullout leads. Simulation procedures are used to evaluate the overall performance analysis of the designed yards. The results of the computer simulation demonstrate the effects of a variety of layouts on the yard capability. However, the layout alternatives have been carefully created by specialists, and importantly the programming simulation tools are employed merely for performance examination.

Yard efficiency evaluation at the tactical management level has been studied by Marinov and Viegas (2011), using analytical modelling and event-based simulation for analysing and evaluating flat-shunted yard operations. The model of the Gaia Flat-shunted yard estimates processing capabilities of deterministic inter-arrivals and time-dependent stochastic interarrivals. The model created includes the yard subsystems to help comprehend the behaviour of each subsystem. The right management of the static resources (number of tracks, sidings) and dynamic resources (rolling stock, crew) is a crucial component to ensure high-quality rail service.

In Crainic and Laporte (1997), operation research methods are used to demonstrate how cargo transport challenges could be mathematically modeled for rail yards at the classical decision-making levels. The authors indicate that the extensive data required and the running times for the computer simulation make the use of another set of yard layouts and operating policies impractical. Consequently, Network optimizing models are commonly used.

Network optimization integrates a traffic multimode route with overall policies aiming to establish global strategies to improve performance and reduce costs. The goal function identified could include generalized costs, for example, the handling costs associated with the wagon classification(sort/block), moving costs, delays costs, and other variables to select the relationship and trade-off among various options.

Crainic (2000) analysed network design models and presented some variables to take into account when designing a terminal/interchange. The complexity of the decisions and trade-offs associated with the network and in terminal operations require an emphasis on the functionality of the yard. The work of Ballis and Abacoumkin (2001) looks at technology of lifting equipment to create a user-friendly expert system for terminal layout and equipment decision based on user parameters and transport demand. The costs curves are used to assist the financial investment decision. Figure 27 illustrates the decision techniques on the lifting expert system.

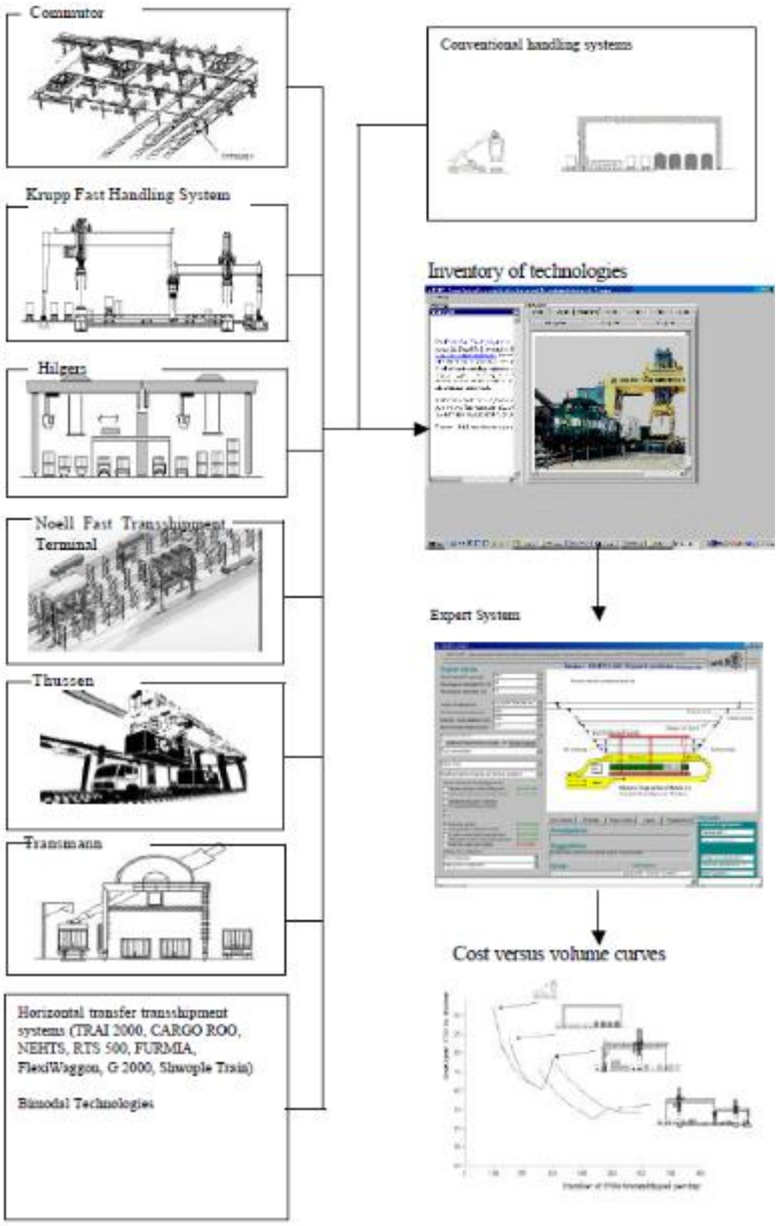

Figure 27: Transhipment expert system software showing the suitables equipment based on the transport demand.

The system suggests the total system cost has to be reduced while satisfying the demand for transport and service standards. The work of Ballis and Golias (2002) supports a multimodal planning strategy, considering the typical elements on rail-road terminal:

- Rail sidings for train/ wagon storage
- Lifting tracks (tracks under transshipment equipment)
- Storage or buffer lanes

- Loading and driving lanes for the vehicles
- Gates, interior road network.

Depending on the transport demand, a variety of types of terminals are contemplated. The size of the terminal for example or lifting equipment available could impact the performance of the service. On one hand, terminals with reduced rail interface have lower infrastructure cost but on the other hand, they potentially have higher operating cost as they require that long trains be divided into two parts to be accommodated in the short lifting tracks.

The investigations carried by Bontekoning et al. (2004) find four differences in intermodal terminals operation. First, the fixed schedules for intermodal transport without classification of origin-destination, while commonly conventional, trains run solely when fully loaded and with many classifications on intermediate nodes. Second, the fleet management is further complicated by the separation of the transport unit (flat wagon) and the load unity (container/semi-trailer), which may be discovered in different technical specifications and sizes. Third, in the interchanges, the intermodal freight (load unity) should be transhipped from one train to another, instead of shunting rail wagons, eliminating the need for rail yard for classifications. And finally, the site of the interchanges is different, as it involves connections with at least of two types of infrastructure road-rail.

Bontekoning (2010) demonstrates a static-process analysis to examine interchange performances and find, technically and operationally, the interchanges models are a valuable contribution to intermodal transport. The challenges of the interchanges are still a challenge for the development of the interchange conception.

Also, the nature of the various stakeholder's needs engaging in the decision-making process for the interchanges indicates a need for another approach. The methodologies developed so far have been confirmed helpful to examine yards capacity/performance but unable to recommend layouts and equipment under user constraints automatically.

2.3.5 Chapter Conclusions

There is much evidence for a growing awareness of the importance of rail freight services. The benefits of a highly efficient interchange include reduced congestion, carbon emissions and pollution, and reduced logistic costs and other improvements in the quality of life. Interchanges and terminals have many topologies, operation patterns, including multi operators, full automated transhipment operations, and multiple services connected within existing urban logistics systems.

The classic approach to terminal design focuses on the rail operation requirements. Such approaches, however, have failed to address to the other stakeholders involved in the rail freight operation such as client, terminal operators, and 3rd party logistics. The increasing need to satisfy multiple requirements of other stakeholders indicates that additional services and different operational patterns are required to improve the competitiveness of the rail in the freight market.

The interchange size and elements need to consider the transport demand and the operational patterns utilized by the rail operator and cargo handling system. Efficient transhipment equipment for one specific interchange might be inefficient for other. Therefore, the technology used and the costs of the cargo handling equipment directly impact interchange efficiency. To develop the interchange simulation tools, the decision maker needs to be able to introduce in the software the costs (or other key performance indicators) related to multiple equipment and infrastructure. The different operational patterns also need to be available for the user to understand the potential impact of the elements for the desired transport demand.

Chapter 3 : Simulation Modelling of Rail Operations in Terminals/Interchanges.

The main objective of this chapter is to present an overview of simulation modelling research to analyse how rail operations in rail freight terminals/interchanges are modelled to improve the performance of operational systems of the railway network. Although the software intend to cover the three levels of planning the focus of the applications developed is on strategic level decisions. The research questions addressed here are:

What are the most relevant features in the existing rail simulation modelling tools?

What are the gaps in the tools for designing rail freight interchanges to satisfy multiple decision makers' requirements?

3.1 Introduction

Planning a rail freight interchange is a complex task involving multiple stakeholders. Planning rail freight operations to achieve greater efficiencies satisfying the requirements of the stakeholders requires a more flexible and reliable transport infrastructure.

Computer simulation is a valuable tool for planning rail infrastructure and operations. Once developed (and calibrated), the simulation models can help to analyse alternatives, measure impacts, costs of different assets, and operation patterns. Simulation models enable the decision maker to test and evaluate scenarios quickly.

Historically, simulation models have been created for railway systems with multiple uses: for calculation of transport demand; for estimating the need of rolling stocks; comparing lifting equipment; workforce/staff , depots, container terminal location and many others. Effective railway simulation models enable decision makers to identify bottlenecks leading to a more comprehensive solution. In the rail sector, generally, the focus is on train movements and delays helping to discover potential problems and possible constraints, which is particularly useful for medium and long-term planning in a railway business environment (Banks, 1998).

According to Pidd (1996), the relationships among system elements and the way they interact determine how the overall system behaves and how well it met its overall purpose.

3.2 Basic Concepts of simulation

In order to understand how the combination of components that act together to achieve a certain goal is important to clarify some basic concepts of simulation.

<u>Time: Static versus Dynamic Simulation</u>

In static simulation, the system output (response) at any instant depends only on the value of the input (excitation) at the same instant. Therefore the system is represented at a given instant, (not changing over time), for example, an Integral calculation of function by the Monte Carlo method.

Lo and Stezo (2004) point out that static models usually not allow the study of changes in travelers departure time, dynamic queuing locations and

duration, non-recurrent congestion.

In Dynamic simulation in other hand side, the output at any instant depends on present values, therefore a particular state might change over the time. For example: simulation of a vehicle manufacturing process. Lo and Stezo (2004)comparison between static and dynamic suggests that under reduced demand conditions, both paradigms could produce similar results, however for higher demands other aspects can be directly opposite

Random: Stochastic versus Deterministic Simulation

Simulations models could be classified stochastic or deterministic considering the random nature of the models

Stochastic simulations are performed using probabilities. Therefore, the behaviour of the system depends on probabilistic variables, for example in queues in which the arrivals occur in accordance with some probability distribution. Several simulations are required to provide the mean of the results and an estimate of the system expected performance. In contrast, in Deterministic Simulations, the system does not include any probabilistic variable (random); therefore, the output of the model for any given input can be achieved in all future simulations. The disadvantage of simulation models with deterministic data is that in the case of average data the individual impact of each value cannot be observed

State: Discrete Event Simulation versus Continuous Simulation.

In Discrete Event Simulation (DES), the changes of state in the system are produced at a discrete point in time, normally triggered by events. In continuous simulation, the state or value of the variables continuously change over time.

3.3 Rail Freight Modelling

Over the last decades, a number of countries have developed freight transport models to support future transport policies and infrastructure investment decisions. Simulation methods in transport can employ a selection of theoretical concepts, including probability and statistics, differential equations, and numerical methods. Freight simulation models usually include studies dedicated to commodity flow, corridor and system capacity, traffic assignment/network flow, and freight plans that involve travel demand forecasting.

To distinguish between the different meanings of transport models, Holguín-Veras et al. (2001) describe the freight transport models in 4 main categories:

1. Regional Freight Model (RFM) referring to freight model designed to predict freight supply and demand at a regional level, considering current and future conditions as part of the forecasting process, for example, in terms of quantity, delivery, and vehicle units. Harker, P. and Friesz, T. L. (1986), for instance, present a nonlinear complementarity formulation to predict intercity freight demand.

2. Market-Specific Freight Models consider freight models with the focus on a detailed description of specific markets. These markets can be defined, for example, in geographic terms (transport corridor), in terms of specific commodities, (e.g., coal, iron ore) in terms of specific transport providers, among other possibilities.

3. Operational Simulation Models refer to microscopic models that are sufficiently detailed to analyse operational patterns, for example, models developed to simulate rail yards or port facilities (see Marinov and Viegas 2011, Holguín-Veras and Walton, 1996), network operation (see Crainic et al. 2001), or to study traffic control schemes (Rathi and Santiago, 1990).

4. Capacity Analysis Models refer to analytical/empirical models that estimate the maximum capacity of a system, considering the maximum flows that can be handled by the infrastructure under prevailing conditions. Capacity analysis techniques can be combined with operational simulation models and queuing theory (as in Marinov and Viegas 2011, Morlok, E.K. and Chang, D.K. (2004)

or be stand-alone models of semi-empirical nature, such as those described in the Highway Capacity Manual (TRB, 2010).

The software package developed focuses on Market Specific Freight modelling and Capacity Analysis Models; however, the package offers the technical parameters for developing microscopic models.

3.3.1 Rail Freight Yard Simulation Modelling

Research into freight transport using simulation modelling tools to study rail freight yards has a long history; extensive previous research to understand freight transport was conducted in the 1970s and early 1980s.

Petersen (1977a,b) proposes an analytic model of railyards using queueing models for train arrivals as a Poisson process, considering different time distributions and the yard resources, marshalling rules, and physical configuration of the yard.

Asad 1980a proposed a multi-commodity network model using dynamic programming for train routing in the planning process of train schedules, considering the interaction between routing and yard activities.

Crainic et al. (1984), considered the interaction between yards and the rail network and proposed a heuristic model for tactical planning using nonlinear, mixed integer, multi-commodity model to identify the best traffic distribution. Cranic and Rousseau (1986) presented a general framework service network and the traffic routing in the context of multi-commodity.

However, despite the extensive research on yard modelling, there is very little published research on the stakeholders that are not directly involved on the rail operation. The lack of research focusing on multi-stakeholders preferences suggests a need for an alternative approach for rail yards simulation models. The multi-stakeholder approach for yard simulation modelling aims to identify the impact of the decisions considering the multi-stakeholders

3.3.2 Levels of Decision Making for Rail Freight Modelling

Considering the planning activity, multiple decision levels can be assigned to the decision-making process, considering the terminal yard and interchanges. Anthony (1965) classified the decision-making at three levels: Strategic, Tactical and

Operational. These classifications have been used by many authors (Assad (2008a) Crainic and Laporte (1997), Marinov and Viegas (2011), Dong (1997) and Caris et al. (2008) to organize the decisions regarding rail terminals.

The strategic decision level is traditionally associated with the long-term vision of the company (or country). It involves high level investments presenting significant impacts on the physical rail network, for instance, relocation of rail facilities or closing unprofitable yards and terminals.

Associated with the medium-term planning, the tactical level normally covers the periods of months/weeks, considering tactical decisions dealing with factors, such as demand operational forms. At this level, research conventionally focuses on the capacity or congestion analysis generally developed.

The operational level is associated with short-term planning, requiring a high degree of information to make short-term decisions (day-to-day, hour-to-hour). This level is dedicated to how the terminal is operated and how the transport plans are implemented on a daily basis to meet the freight transport needs. It typically deals with empty car distribution, locomotive assignment, crew scheduling, and timetabling.

For the objective of this research work, developing tools for planning interchanges, the strategic decision level is especially important. In order to study and develop analytical tools that represent rail freight interchanges, the transport demand and capacity are analysed. Although the software package developed focuses on the strategic level decisions, the tool is flexible to enable creating different settings for tactical and operational level decisions.

3.4 Simulation tools

As discussed in the previous section, rail simulation models have a long history of trying to understand the complexity of the rail system. Simulation models are usually implemented using existing simulation software packages or using programming languages (e.g., C, C++, Python, Java) to develop simulation models. There is a range of simulation packages available on the market with different programming techniques and interface methods. The choice of more suitable tool considers factors such as:

- Main characteristics for the simulation to be performed
- Data availability for supporting the simulation modelling
- Knowledge to develop the tool or to carry out the implementation of the mode.
- Post processing a presentation of results
- Time available to perform the simulation experiments.

3.4.1 Simul8

Simul8 is a multi-propose event-based simulation tool develop by SIMUL8 Corporation. It uses dynamic discrete simulation to enable design and test scenarios.

Through building blocks (Figure 28), the user can drag and drop the blocks in the workflow area. The modelling elements can be edited with double click, enabling editing parameters, such as statistical distribution, tags, batching, and others. The software enables the creation of a simple and more advanced model using the visual Llogic editor. The basic components of Simul8 are the work item (entity), meaning the moving element of the simulation.

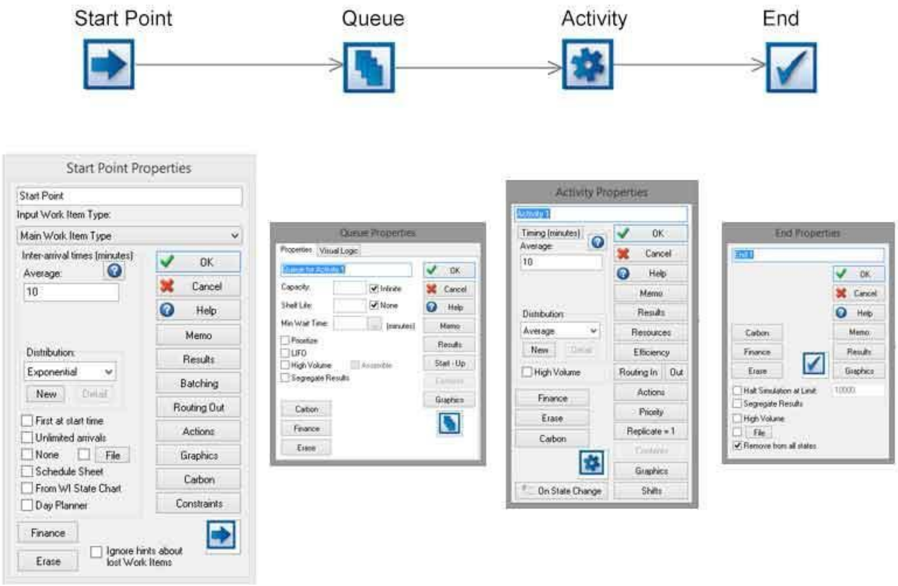

Figure 28: Graphic representation of the main simulation elements and basic options of Simul8

The "Start point" icon represents the arrivals of the entity on the system, for example, products arriving in the production line or queue or representing rail wagons arriving at classification in yards. The "Queue" icon represents a storage zone or the accumulation of work items (entity). "Activity" icon represents a work centre or a process to be developed on the system. "Resource" icon represents constraints or need for the activity be developed. "End point" icon represents the output of the simulation. To run simulation experiments, all components need to be connected by arrows (route), representing the logic flow of the model. Characterized by the inbound and outbound process, the activities in Simul8 can be modelled considering constraints on the activities (e.g., resources required to process, special tags).

With a double-click, the simulation elements can be customized to represent the real system to be simulated. At the start point, for example, different distributions can be assigned. The users also can create their own distribution, based on real data. More complex modelling tools can be developed using the Visual Logic editor.

After the creation of the simulation conceptual representation dragging and dropping the basic building blocks in the workflow area illustrated by Figure 29, the resources required for the activities and graphical representation of the process can be displayed to show in real-time the performance of the different building blocks

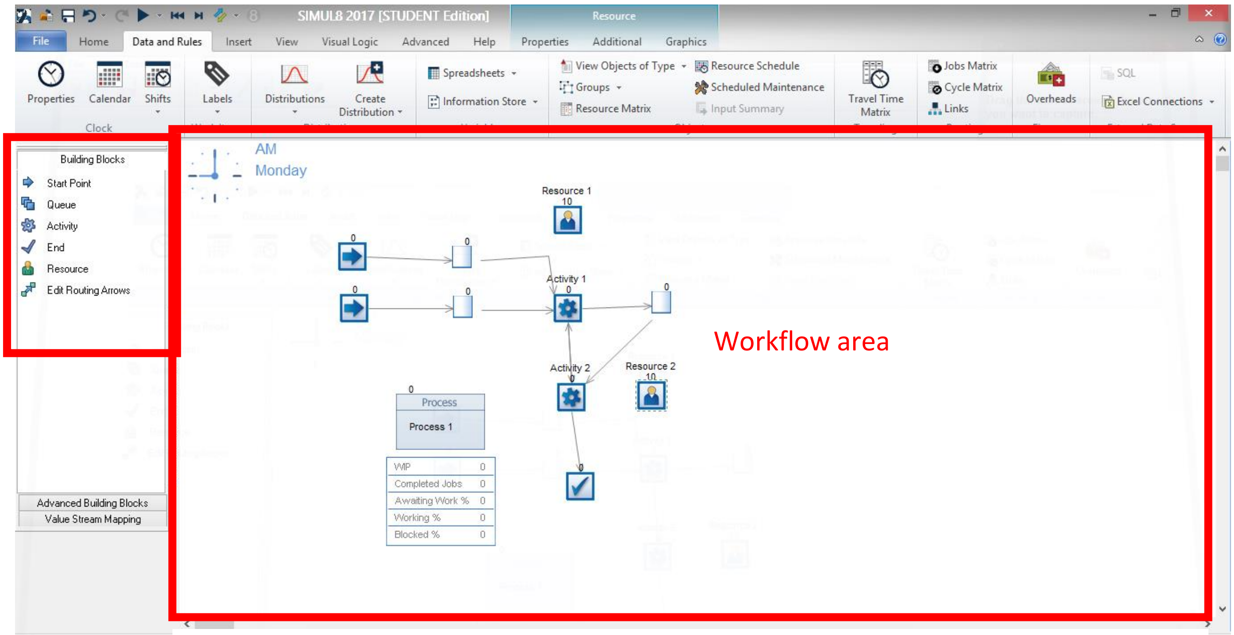

Figure 29: Simul8 workflow showing the basic elements placed in the workflow area

.

The speed and the durations of the simulations illustrated by Figure 30 can be defined by the user clicking on the first tab (Home).

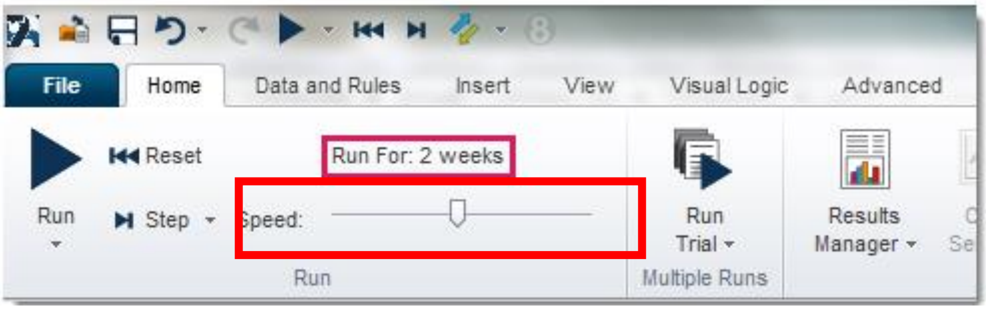

Figure 30:Simulation duration and speed adjustment- Simul8

Over the last few years, a considerable number of studies has been published using Simul8 for analysing rail infrastructure. A flat-shunted yard is studied by Marinov and Viegas (2009), considering the different tracks as segments modelled in Simul8 as “activities” to understand the behaviour of the processing capability of a Portuguese rail line. Abbot and Marinov (2015) analyse Interchange alternative designs to evaluate the HS2 (High Speed Two railway) integrated with conventional networks. Wales and Marinov (2017) investigate delay mitigation strategies in Tyne and Wear metro with Simul8 to improve operation efficiency.

Looking at the main advantages of the Simul8 package, should be noted that Simul8 reduces the need for analytical tools to study the system, especially systems with more complex interactions that can become computationally complicated in modelling though analytical tools. The compatibility with external programs, such as Excel, and the extensions for statistics and graphical animations help to export results and create reports.

Mastering programming languages is time-consuming compared to understanding mathematics and statistics; therefore, Simul8 and similar simulation packages potentially can contribute to enhancing rail efficiency, lowering the technical requirements to evaluate rail systems. However, despite the lower complexity compared with programming languages, the construction of simulation models still requires special knowledge/ training, as Banks (1998) points out, due to the difficulty of interpreting the obtained results. The use of the incorrect statistics might compromise the simulation experiment results and the investment decision.

From the users' point of view, despite the simplicity of the drag and drop feature, understanding all options available in each element and how they need to be configured can be a complex and time-consuming activity.Figure 31 illustrates the number of submenus and options.

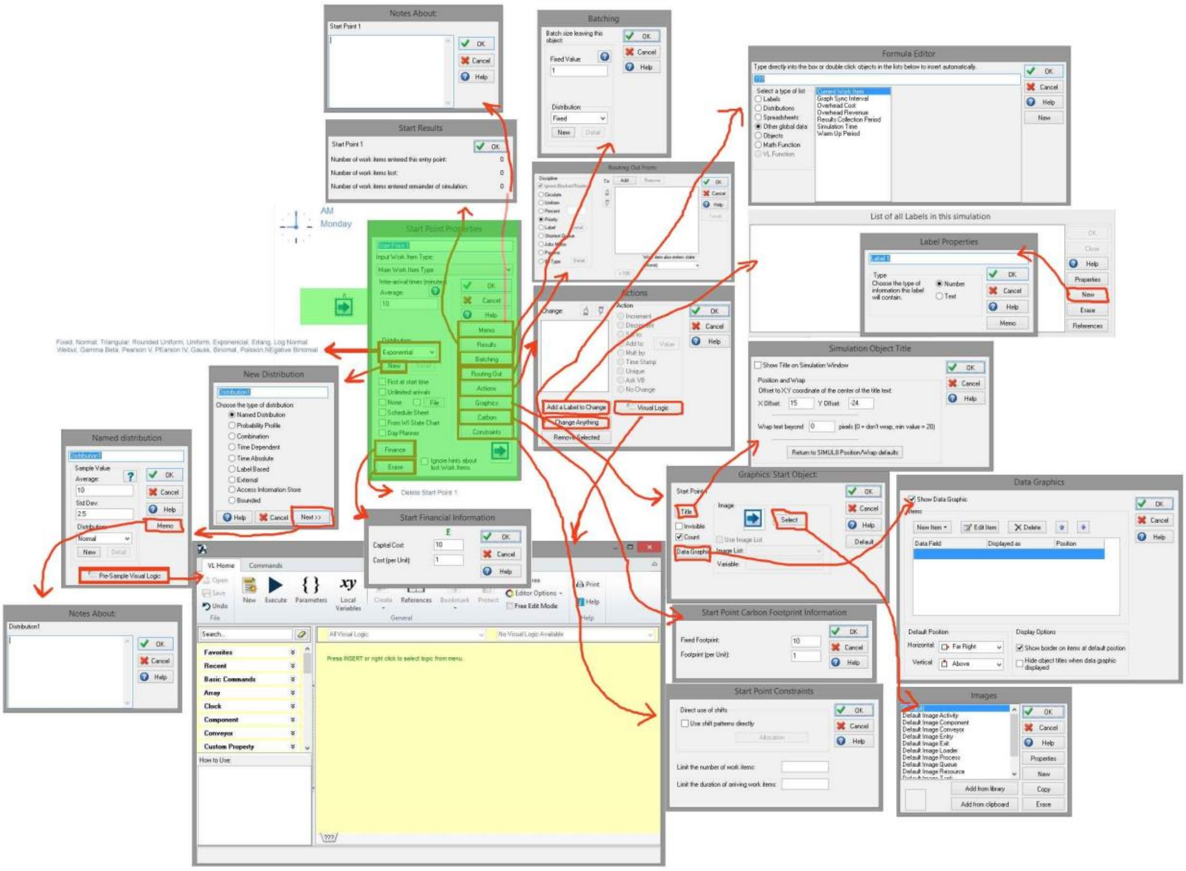

Figure 31: Menus and sub-menus with options- Simul8

Despite the complexity of the model creation, after the model is validated, the software enables the user to play with data through alternative input insertion/ modification to test scenarios to improve system performance, without causing disruption to the real system. The possibility of modelling a complex simulation through the Visual Logic editor is another advantage of the Simul8. Bottlenecks and system restrictions can be easily identified, providing an understanding of their causes and consequences.

In conclusion, the development of multi-stakeholder analysis is not supported by Simul8; however, the software package enables a more simplistic modelling environment compared with other simulation tools; therefore, it is potentially easier to learn and use. Small simulation models can be developed in a short time and tested thought short simulation runtime. The user-friendliness of Simul8 with the drag and drop elements is also a strength of the software used in the simulation tools developed in this research work. However, a fair knowledge about rail operation and simulation by the user it still required.

3.4.2 Arena

Arena is a discrete event simulation software commercialized by Rockwell Automation. Originally developed by Systems Modelling in 1993, Arena uses the SIMAN processor and simulation language. Used by hundreds of universities and colleges worldwide, it is one of the most widely-used simulation tool in the market.

Arena is widely used in different areas; typical examples of simulations include manufacturing, healthcare administration, call center support services, system analysis, and analysis of customer relationship. ARENA package includes the ARENA simulator, the Input Analyzer, and the Process Analyzer analysing the output. Figure 32 illustrates the Arena user interface.

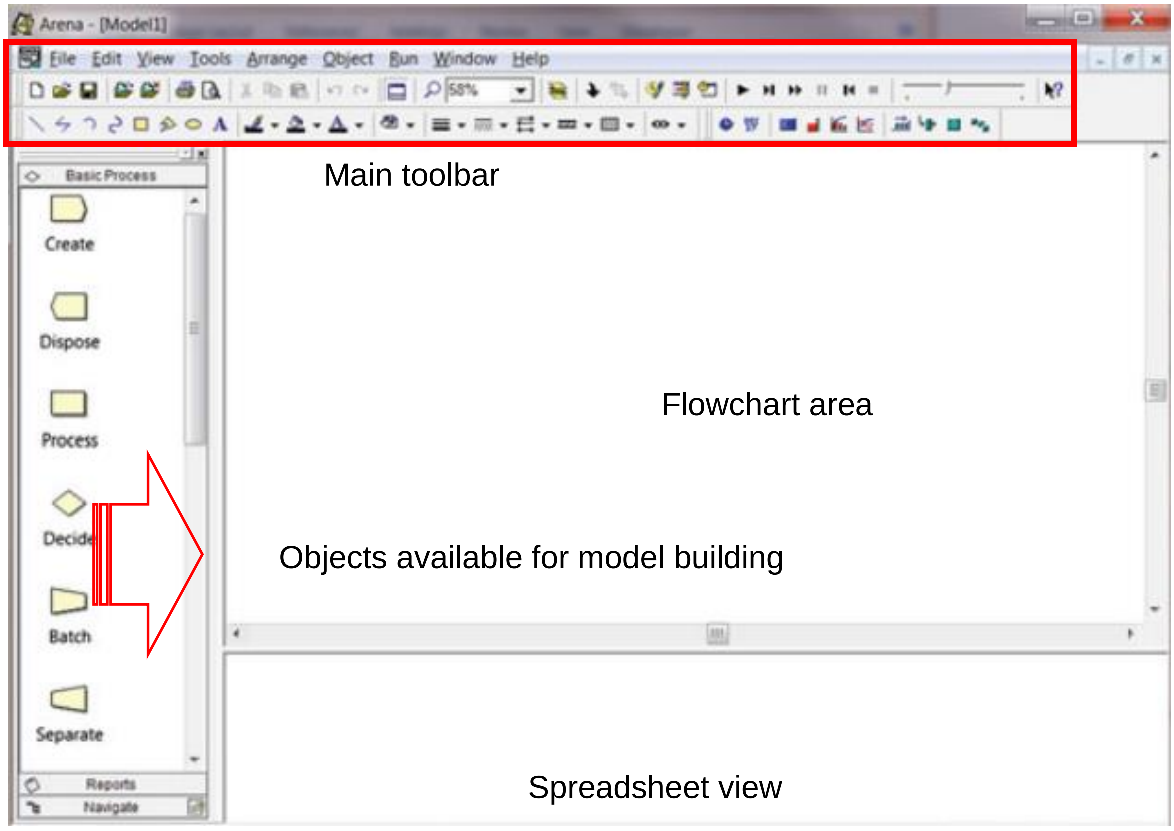

Figure 32: Menus and sub-menus with options- Simul8

The main toolbar contains "standard" elements to create a new model, saving model, opening previously saved models etc. Also, it allows the start of the simulation, speed up/down, or stopping of the simulation in the toolbar. The models are constructed using the drag-and-drop elements on the Flowchart area. Figure 33 shows an example of flowchart of voting-systems modelled in Arena (Allen 2011).

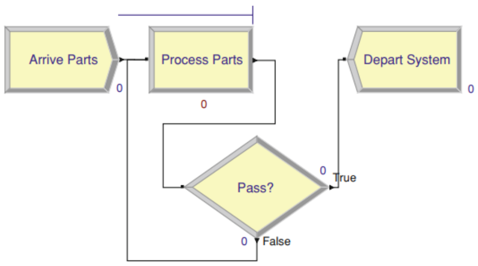

Figure 33: Arena flowchart voting system example

Arena also provides a number of pre-developed templates, which are objects and modelling reusable elements grouped into panels, allowing the description of processes in an easily interactive and organized way. By using, for example, a specific industry template, the appropriate terminology is loaded, saving time and effort for the simulation designer.

Arena has been specifically used for modelling rail freight yards design and operations by Fioroni (2007) to analyse the closed cycle of Brazilian rail networks. Netto et al. (2015) used Arena to analyse the capacity of a port terminal (Ponta da Madeira) to export iron ore. Scenarios for capacity for the terminal are developed considering three interconnected subsystems to identify cradle occupancy and possible bottlenecks in the system. As it can be seen in Figure 34 the complexity of the model and the number of variables used indicates a need for reliable data.

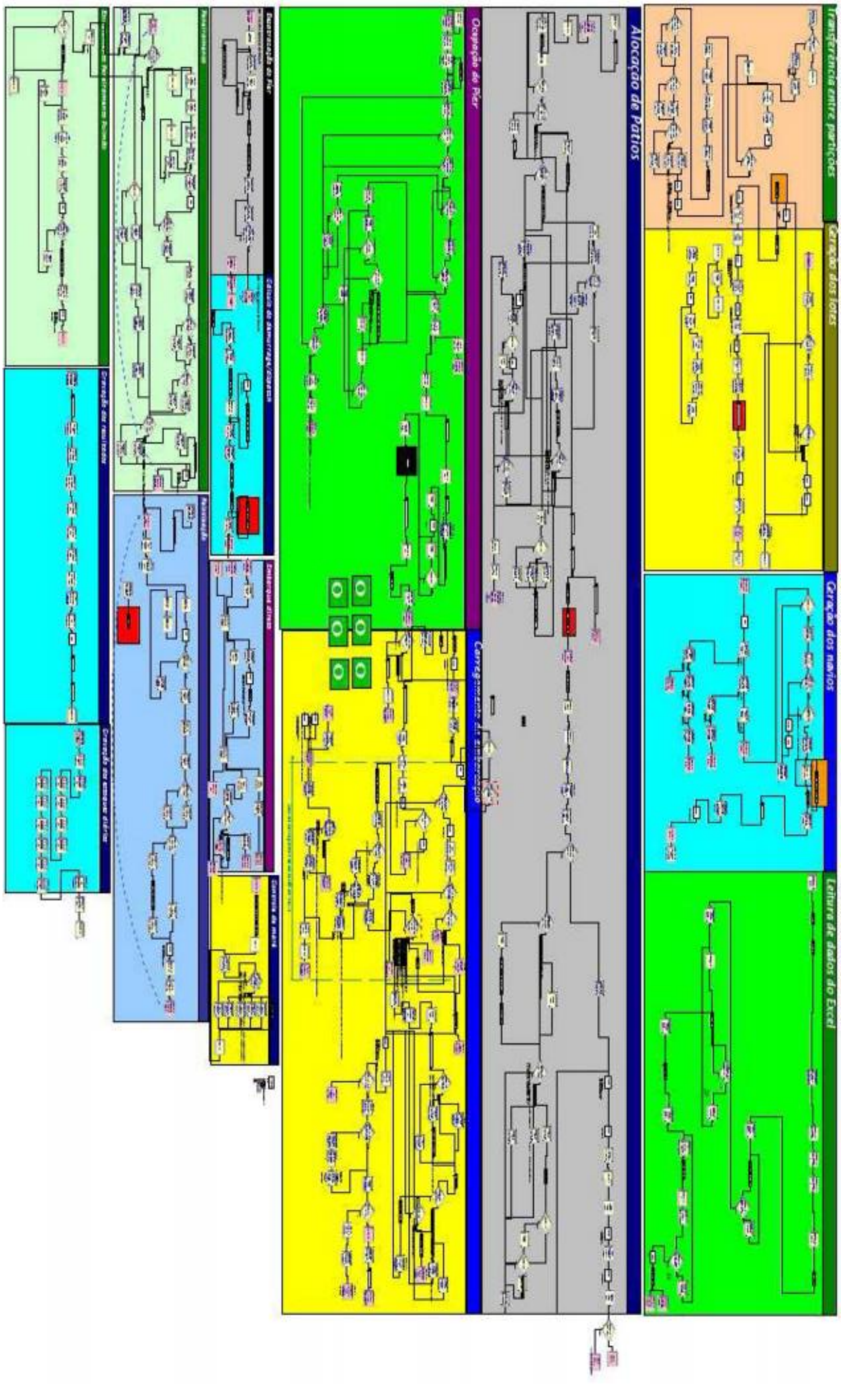

Figure 34: Iron ore rail operation flowchart layout (Netto et al. 2015)

Ponta da Madeira terminal was studied by Carneiro (2008) to identify the impact of different production scenarios and operating models of the Brazillian mines, Carajás iron ore (CVRD/SA), as well as changes in the terminal layout (Figure 35)

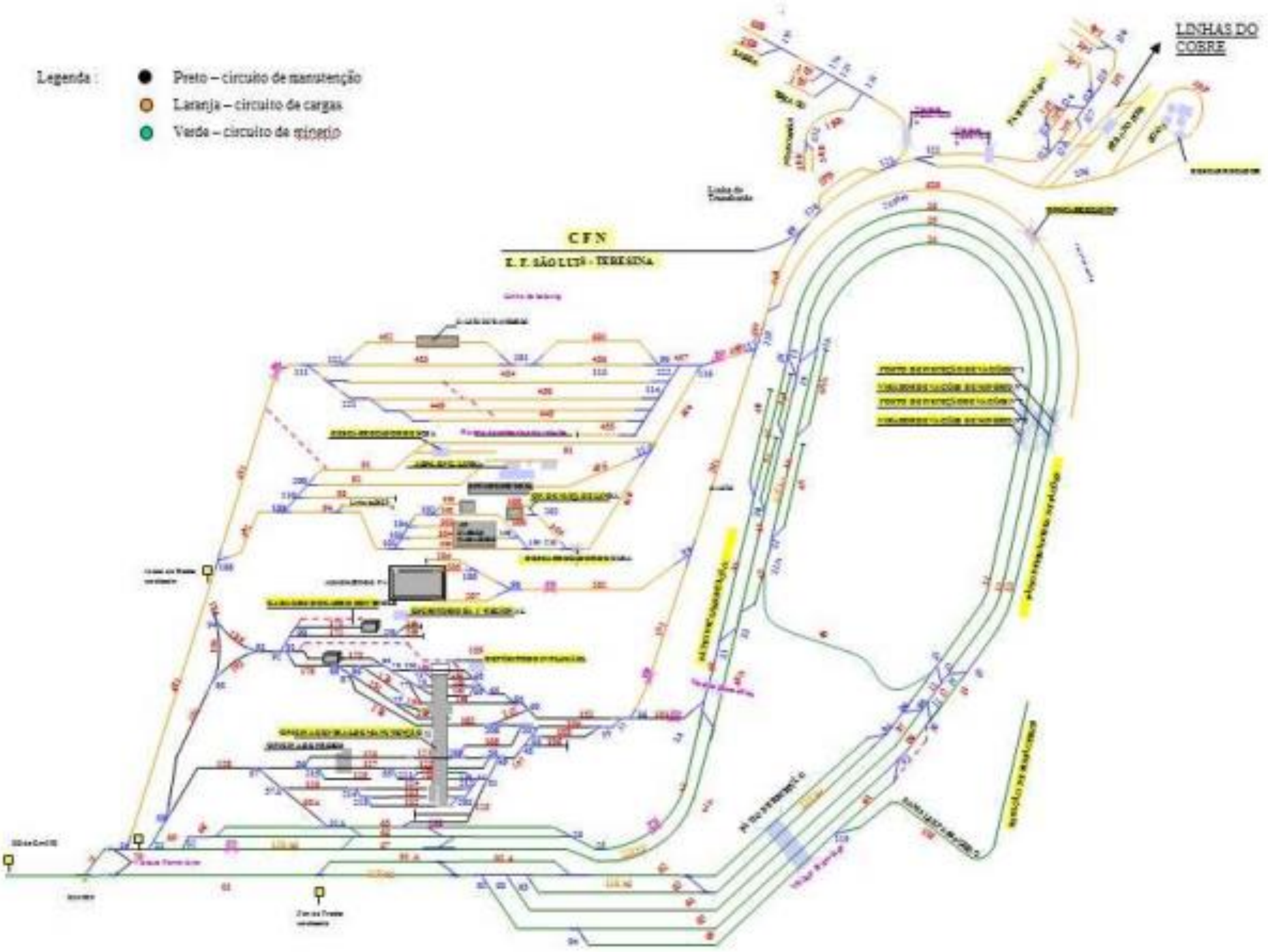

Figure 35: Iron ore rail operation simulation

Netto (2006) , in his master's thesis, also carry on a simulation of the iron ore production chain in Brazil, using the Samarco S/A (mining company) database to identify the lowest operating costs, considering inventory, operating costs, maintenance, and others.

In Europe, the utilization level of rail freight has been analysed by many authors; for example, Woroniuk and Marinov (2013) used Arena to simulate freight in Spain. Motraghi and Marinov (2012) propose urban logistics using Tyne and Wear metro infrastructure, and through Arena simulation, illustrate possible outcomes of the operation.

Advantages and disadvantages of Arena

Arena software is also a graphical environment with integrated simulation. In the modelling process, the user does not write code lines. The drag and drop blocks similar to Simul8 enable creation of a simulation in a graphic and visual way. The user only writes code lines to import and export data from Arena to other platforms, for example, Microsoft Office Excel or "Text Document" (.txt).

The visual simulation of the process helps to identify if existing logics and simulation rules were implemented correctly and represent the real system

Although the focus is on dynamics simulation, Arena can handle continuous and discrete, deterministic and stochastic simulations.

According to Kelton et al. (1997), Arena combines the facility of use of high-level simulators with the flexibility of programming languages, enabling, if required, a simulation of the real system.

Due to the high complexity of Arena, extensive experience with a simulation modelling package is required. Also, the multi-stakeholder analysis is not supported by the package. Most of the research published using Arena focuses on rail operational efficiency.

3.4.3 Witness

Witness is simulation software from the Lanner Group in two versions, Manufacturing Performance Edition and the Service and Process Performance Edition. The tool is available in multiple languages and has been used in several academic studies (Garcia 2013, Shabayek and Yeung 2002, Parola and Sciomachen 2005).

The user interface of WITNESS, shown in Figure 36, presents the tree view of the model, an assistant tree, time displays, designer elements (similar to the Arena building blocks).

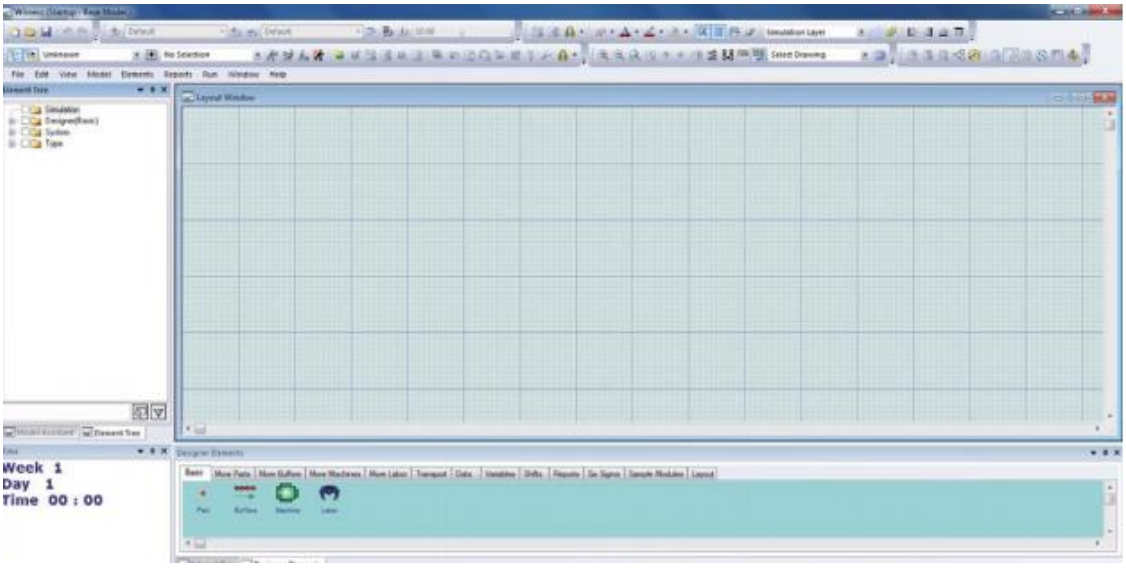

Figure 36: Witness user interface

Figure 37 (Waller 2012) shows two further examples of the designer element palettes. These palettes can be added to by Customers, both new palettes and new elements.

Figure 37: Witness templates options

Witness Scenario Manager enables a number of ways to present the results of the simulations. The user can choose and customize their own way to run and analyse experiments creating a customized report. The SQL repository offered stores and sorts all simulation results in a library. Examples of charts available, provided by Waller (2012), are shown in Figure 38.

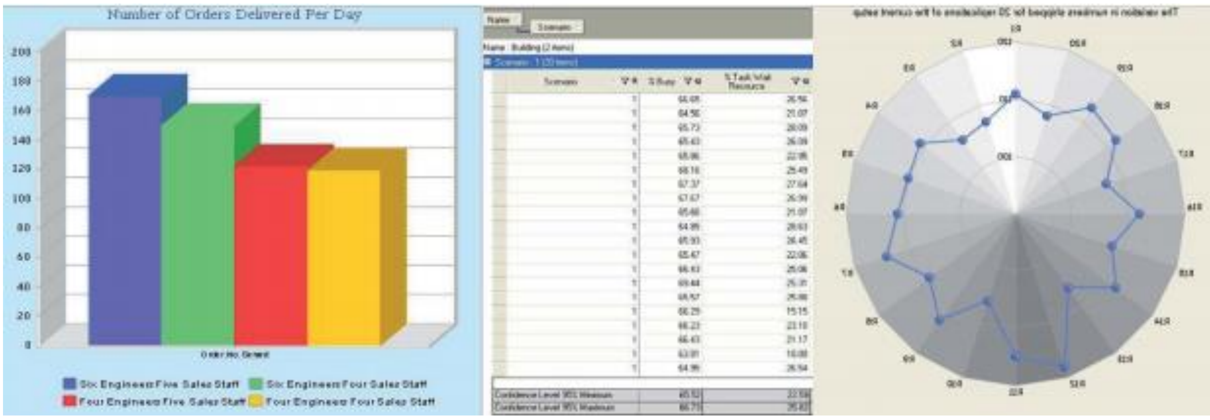

Figure 38: Witness simulation results and charts

Witness uses and features

A large and growing body of literature has investigated port terminal design using Witness. Shabayek and Yeung (2002) analyse the performance of Hong Kong's Kwai Chung container terminal, showing good results in predicting the terminal performance.

The intermodal network of the Italian ports of the Ligurian was analysed by Parola and Sciomachen (2005). Carteni and de Luca (2012) developed a witness model focused on terminal model set-up, its calibration, and validation. The conceptual model developed by the authors suggests high complexity and interdependence of the simulation elements.

Garcia (2013) proposed a simulation tool, combining Witness with a spreadsheet interface, for the user to introduce their inputs in MS Excel and evaluate intermodal design alternatives to improve existing terminals. A similar approach is proposed in Garcia and Garcia (2009), with a case study to illustrate the model implementation. The model enables simulating alternatives through the introduction of required data into a user-friendly interface, potentially helping users with no previous background in simulation to evaluate different alternatives.

Another advantage found in Witness package is the visualisation tool features, including 3d models and animations, helping the stakeholder visualise the simulations and the movements of the components.

3.4.4 Anylogic

AnyLogic is a simulation tool based on Java and the Eclipse framework to model and combine different systems in the same model (Discrete Events System, System Dynamics and Agent-Based Simulations). AnyLogic package provides object-oriented elements and visual tools for user-friendly modelling, as well Java code for enabling expansion through user's Java code, customizing the model according to the particular needs. UML standards (Unified Modeling Language) structure diagrams can be used for developing hierarchical models.

Compared with the previous tools, the models can be more intuitively decomposed into the blocks. In the palette section, AnyLogic provides a number of libraries for fast modelling. A specific library for rail (Figure 39) enables modelling rail infrastructure.

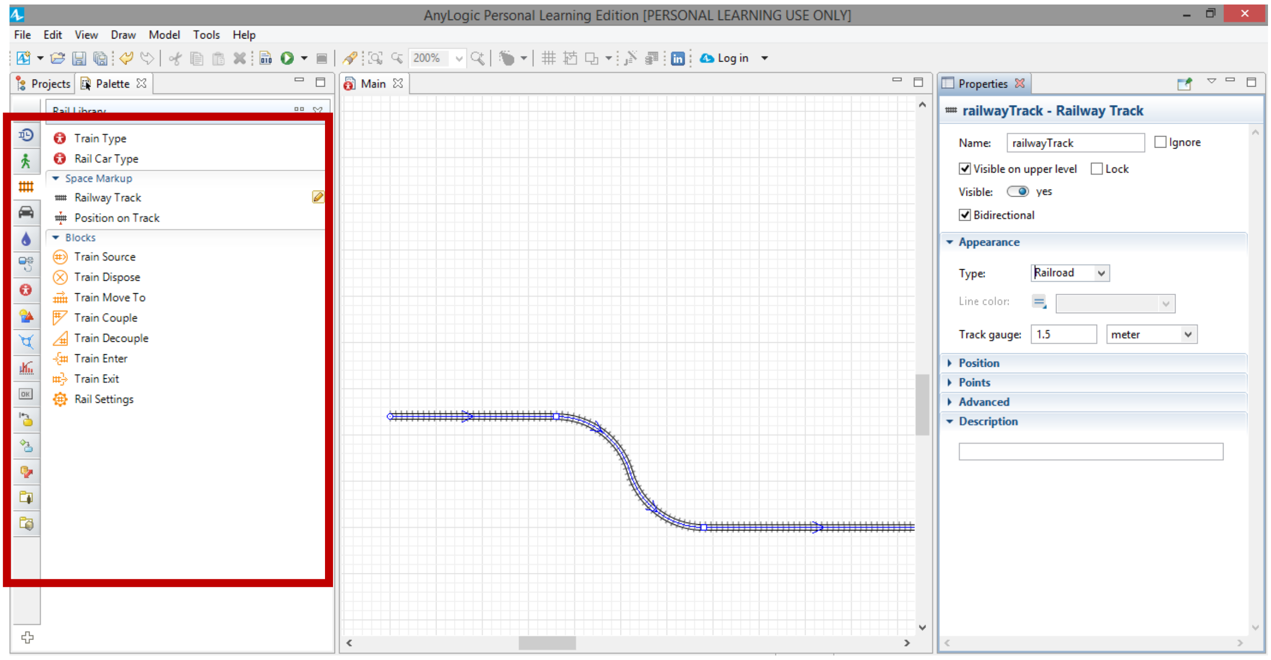

Figure 39: Anylogic user interface showing the library for rail

<u>AnyLogic uses and features</u>

Model exportation and the cloud model execution enable running simulations faster and more flexibly. Sophisticated animation using 3D elements (similar to the Witness package) can be used to demonstrate graphically the system interaction.

However, the main advantage of AnyLogic is the use of multiple methods. Modelling the actions of a number of autonomous entities via system dynamics are more efficient for modelling continuous variables compared with Event-Based System. The dynamics pattern developed can also be saved in the library object to be reused in further models.

Grigoryev (2016) analysed the range of abstraction levels for the three different methods (Figure 40).

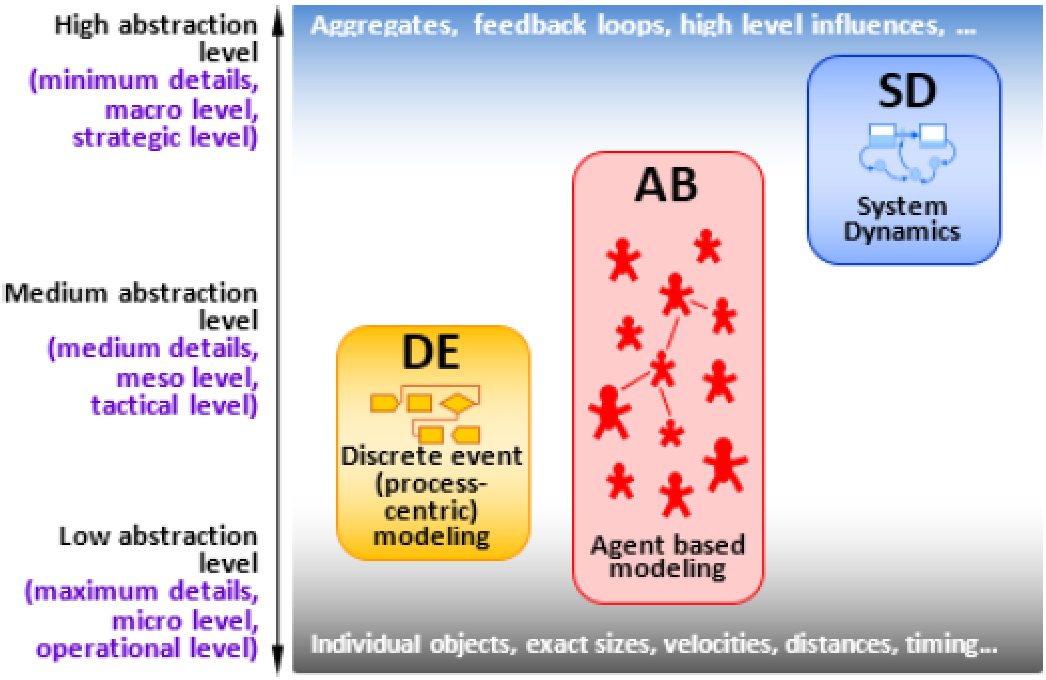

Figure 40: Simulation models available in witness package and abstraction levels

As Figure 41 illustrates, the agent modelling offers a wide range of abstraction, including a high level of abstraction to create individual behaviour in parallel to processes on discrete events system or system dynamics. The agents can follow the process or jump steps in the flowcharts. The creation of agent behaviour is easy, and the software provides additional information about the agent modelling through the help. Figure 41 illustrates the agent creation tool.

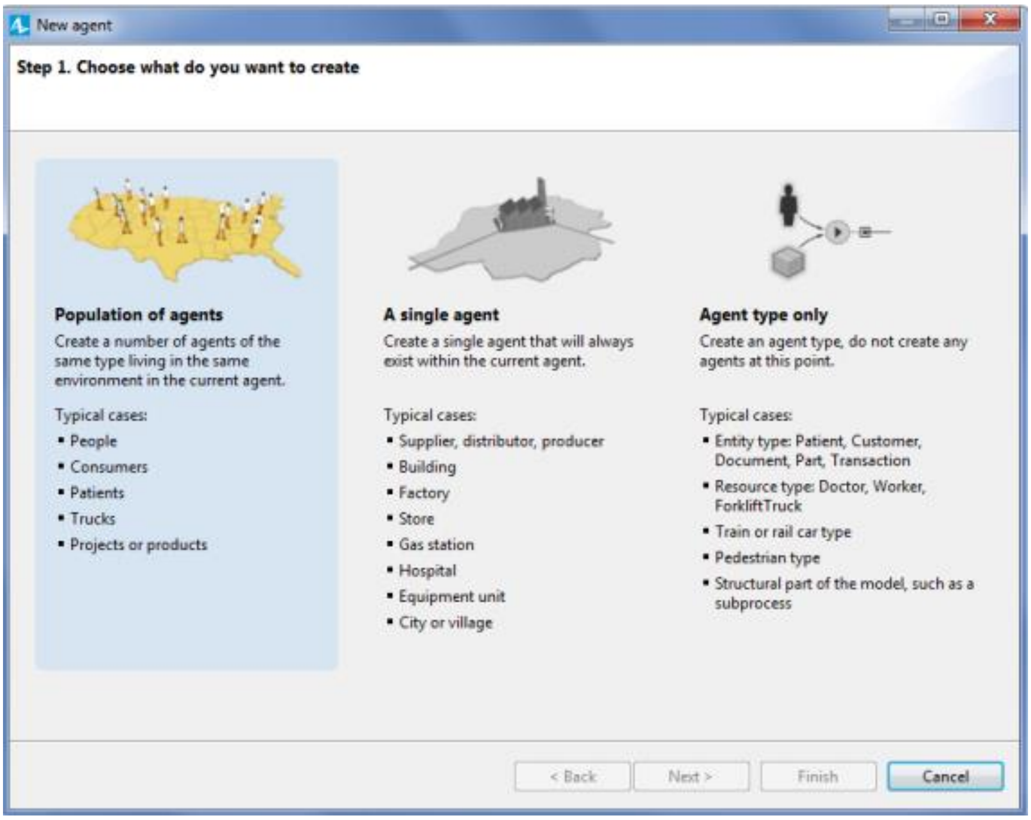

Figure 41: AnyLogic agent creation tool

Zhang et al. (2010) developed a simulation model for observing the dynamic changes of the supply chain. Fikar et al. (2016) studied, from a strategic perspective, the transalpine rail network, considering freight traffic and potential delay of disruptions.

3.4.5 OpenTrack

OpenTrack is a simulation package specifically designed to simulate rail operation. The software is mainly used in Europe, as well as South America, Australia, and Asia. The package was developed by OpenTrack Railway Technology, an ETH Zurich spin-off-company of a research project funded by Swiss Federal Institute of Technology. The aim is to enable modelling complex railway problems. Based on the technical characteristics of the infrastructure and operational data (Figure 42), the package simulates train movement.

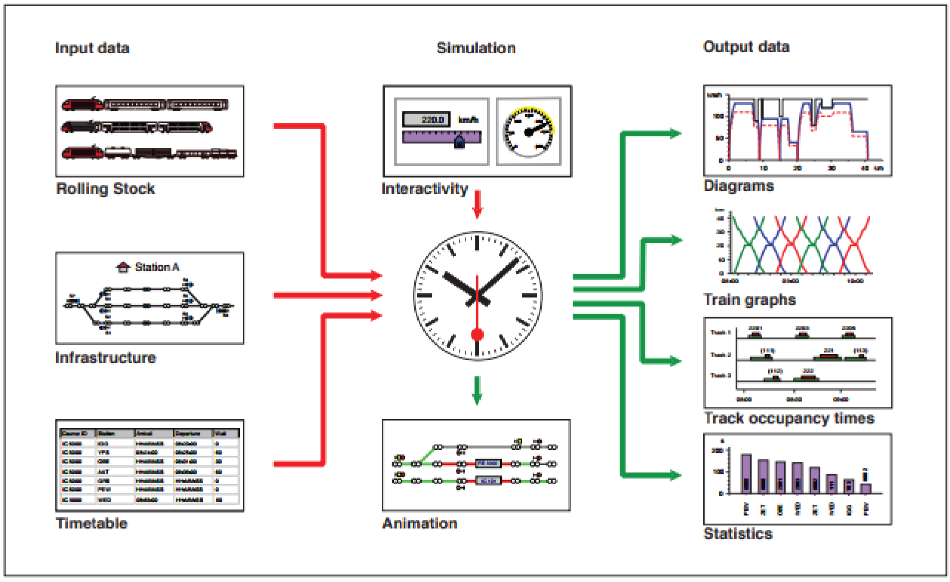

Figure 42: Opentrack simulation components

In order to simulate the rail operation, OpenTrack works with three main different inputs: rolling stock, infrastructure, and timetable. Rolling stock technical characteristics can be recreated in great detail. The user can define the tractive effort of the equipment in use, weight, and maximum speed. The Formula of Strahl is used to calculate the resistance of traction vehicles (Huerlimann 2001):

$$R_{LT} = g \cdot \{[f_L \cdot \frac{m}{1000}] + [k_{StI} \cdot ((v + \Delta v) \cdot 3.6)^2]\}$$

where:

Rlt = Train resistance

g: Gravitational acceleration (9.81 m / s2)

m: mass of the traction vehicle

v: speed

Av: supplement speed (15 km / h = 4.17 m / s)

fL: resistance factor (default value: 3.3).

The rail infrastructure is modelled with lines and vertices in special graphs, called double vertex graphs. In this graph, the vertices do not appear alone, but always with an additional vertex. With the conventional graph, a possible route of D-C-B-E-F (Figure 43) could be reversed (F-E-B-C-D); however, since the real switches cannot be traversed in this vertex order, the double vertices control the movement of the trains.

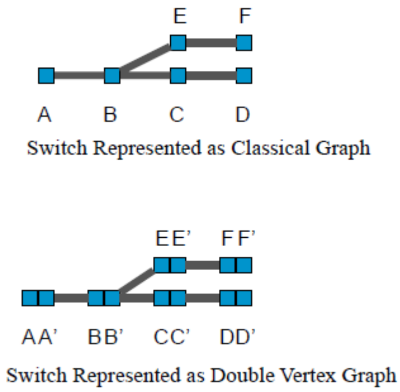

Figure 43: Opentrack line representation

The user can specify various attributes and technical characteristics of infrastructure, such as the lines, stations, signals (e.g., gradient, maximum speed, capacity), and edit the network's topology graphically. After modelling the lines, the user introduces the signalling system to control the train movements. In the simulations, an occupied track blocks the movement of an incoming train. Also, switching times of the signals or restrictive states of signals directly influence the operational performance. After the network is developed, the user can introduce the existing timetable (or the new one) to run the simulations and, through the outputs, evaluate the performance of the different timetables identifying bottlenecks in the infrastructure. A station or terminal requires a high level of technical details, so the simulation can be performed on the Opentrack yard model.

The final objective of *OpenTrack* is to enable user-defined trains to fulfil the user-defined timetable constrained by the user-defined track layout (Huerlimann and Nash 2010).

Opentrack uses and features

Much of the current literature on simulation using OpenTrack pays particular attention to passenger trains. Darlton and Marinov (2015) simulate Tyne and Wear Metro to evaluate the performance of a new rolling stock with tilting technology, considering ride comfort and speed. Pellegrini et al. (2016) propose an optimization algorithm to support dispatchers' decisions modelling 7 km of track of the French infrastructure (SNCF Reseau). Schlechte et al. (2011) develop a microscopic model to convert the results to macroscopic level for timetable development (Figure 44).

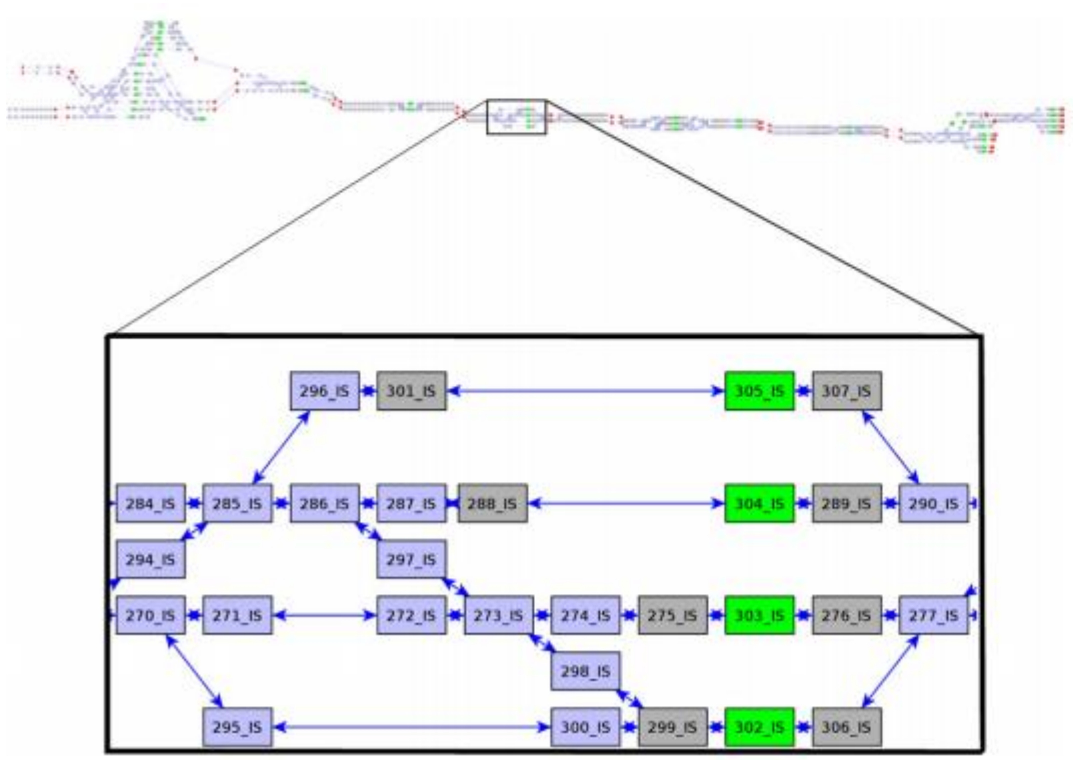

Figure 44: Opentrack bottleneck visualisation

Ljubaj et al. (2017) uses OpenTrack to observe bottlenecks on the system and evaluate timetable quality, considering several parameters.

As observed by Marinov and Viegas (2011), due to the nature of the freight operation patterns, the rail freight performance requires evaluation, considering improvised operation and structured operation. Although OpenTrack enables the user to simulate rail freight operations, the need for timetable makes the package less suitable to simulate an improvised operation.

Some strengths observed on OpenTrack are the compatibility with other simulation packages through the RailML interface (e.g., Viriato) and robustness of the simulations analysis. The possibility of simulating advanced signalling system (ETCS Level 2,ETCS Level 3 or ERTMS) helps to identify potential benefits of implementation of new signalling systems. The energy consumption model (fuel or electric energy consumption) calculated, considering the rolling stock in detail, helps to evaluate the impact of technology applied to rail wagons and locomotives, simulating not only the economics of the train movements but also the carbon footprint of the operations.

3.4.6 Railsys

RailSys is a computer-based package focused on the microscopic simulation of railway networks developed by Rail Management Consultants (RMCON). Changes and modifications in infrastructure or in train operations can be made to test and evaluate possible improvements of the network operation. The software enables a technical and operational planning for railway transport (Bendfeldt et al. 2000).

According to Aly et al (2015), Railsys consists of 4 main elements: infrastructure, timetable, evaluation, and simulation as shown in Figure 45.

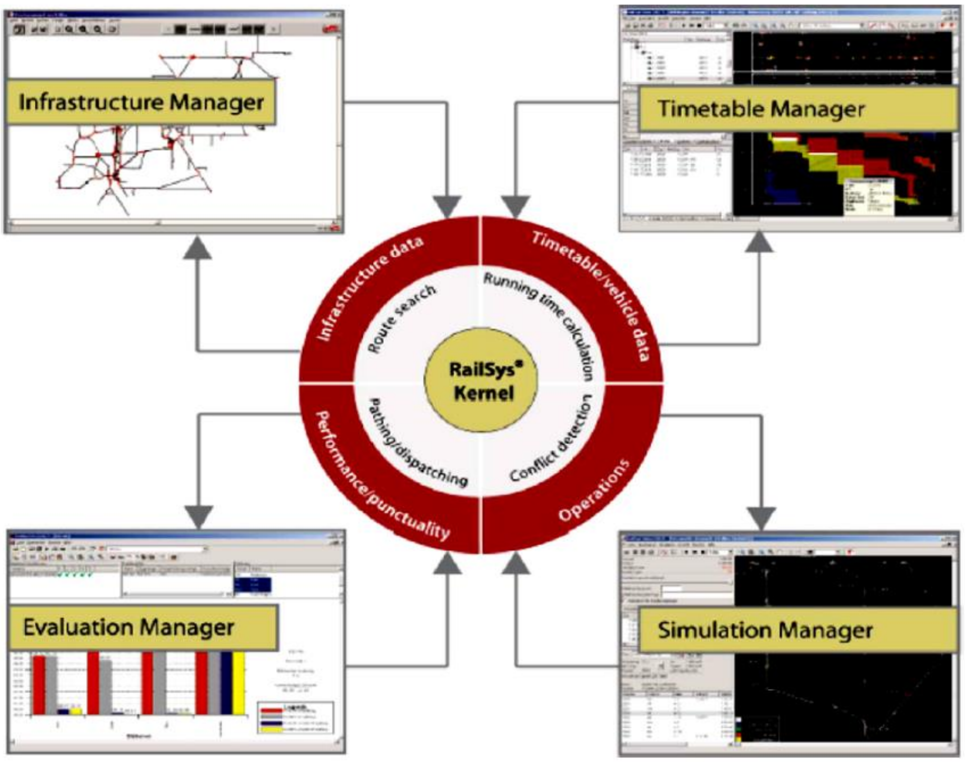

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Figure 45: Raylsys- Simulation components consist of 4 managers: infrastructure, timetable, evaluation and simulation

In "Infrastructure Manager," the data related to the network infrastructure can be inserted in a detailed infrastructure model (signal, control system) with high accuracy (1 meter). The infrastructure data can enable the creation of variants. The simulation can run on the initial network and planned variants in a project to test the effects of changes in the infrastructure changes/timetable.

In the timetable, the use of alternative timetable or rolling stock immediately provides updated running times, enabling verification of the quality and robustness of the planned service. A conflict detection system is provided through data from the timetables.

The Evaluation Manager shows statistics for the planned service, also enabling communication of the results with stakeholders. It offers printable graphic results of the simulation that can be integrated into reports or presentations. A map of the line helps to identify punctuality and possible bottlenecks on the network.

The creation of a simulation on Railsys follows the workflow presented in Figure 46.

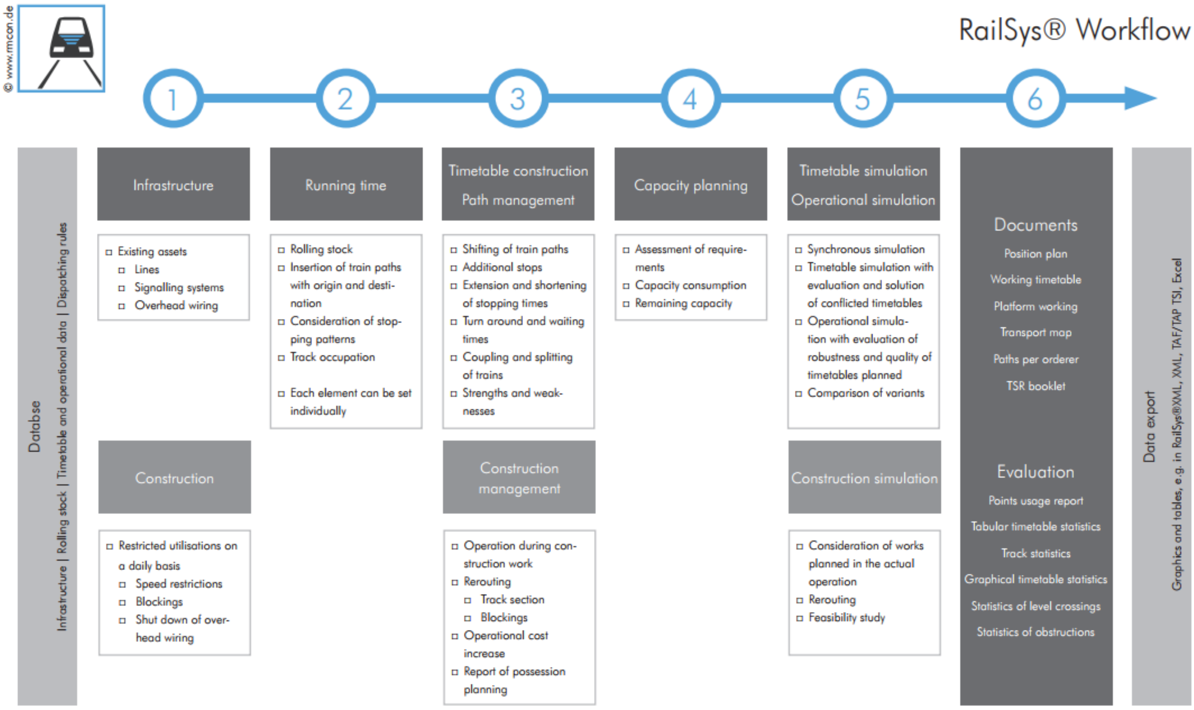


Figure 46: Railsys workflow

Solinen et al. (2017) studied punctuality, applying Railsys to create an indicator for Robustness in Critical Points (RCP), analysing the robustness of the timetable on the Swedish network. Huber and Wilfinger investigated the integration of Railsys with Network Evaluation Model (NEMO) for timetable forecasting (Figure 48).

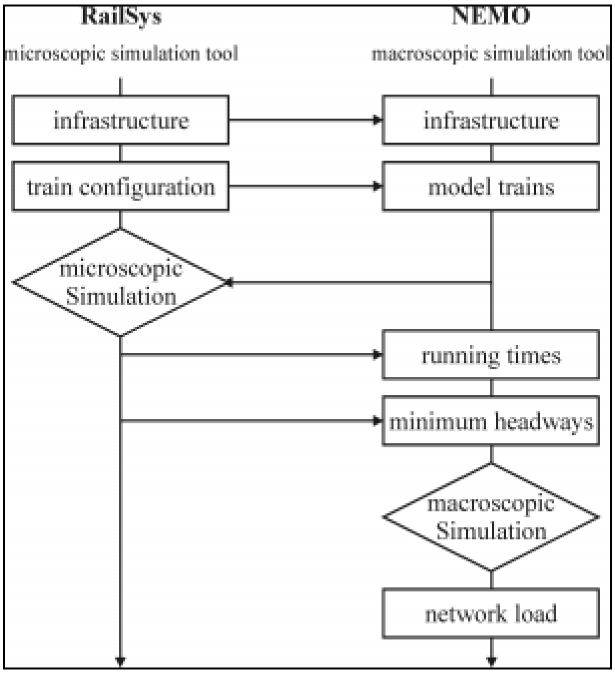


Figure 47: Railsys Nemo integration

3.4.7 Villon

Villon is a simulation tool specifically developed for transport simulation developed by Simcon for analysing investments in design or reconstruction/re-engineering of logistics and transport systems. The simulation supports typical rail terminal issues, such as an increase in the inbound flows, changes in the network with a new timetable, or changes in the infrastructure.

Adamko and Klima (2008) showed the role played by simulation as an effective way to investigate the impacts of new expensive infrastructure before implementing in reality. According to the authors, Villon supports microscopic simulation of a different logistic system, providing precise modelling and visualisation of transport movements to build the model the railway is divided into three subsystems: Resource, Customer, and Control.

In the "Resource subsystem", the user models the elements belonging to the infrastructure defined by Adamko and Klima as fixed resources (static) (for instance, signalling, lines). The user also is able to model elements that can change their location, for example, locomotives, wagons, crew mobile (dynamics) resources.

In "Customer subsystem," the activities to be executed are modelled as trains or cargo, for example, brake inspection, shunting. The input generator created inbound flow in the terminal (arrival of customers/cargo).

In the control system option, the software creates the rules for the decision-making activities based on Kavicka et al. (2007) architecture for creating the automated intelligent dispatcher (ABAsim) shown in Figure 48.

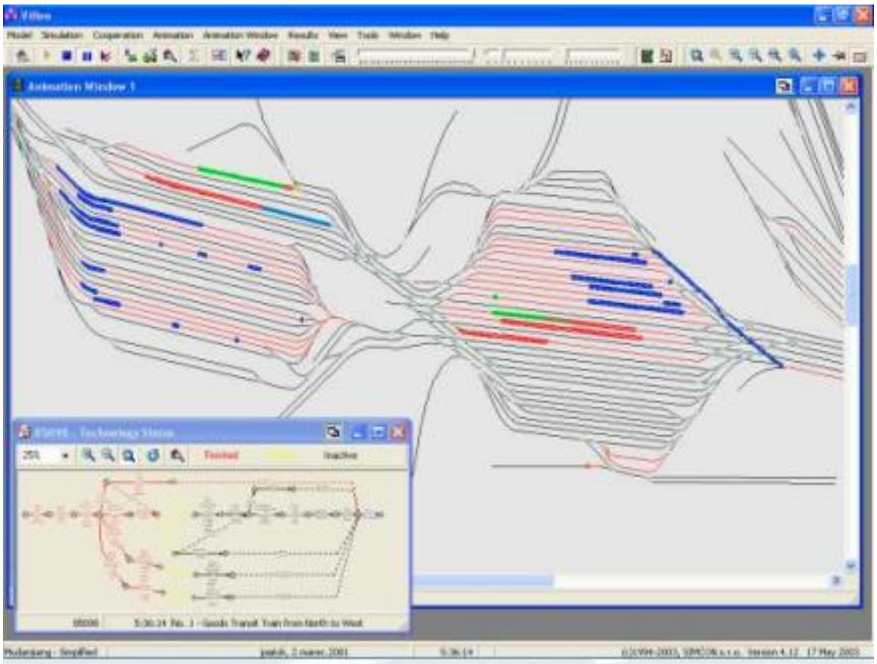


Figure 48: Marshalling yards modelled with Villon architecture

For setting the scenarios to run the simulations, Villon enables the creation of different configurations of resources, customer, and control.

Although Villon supports the decision to design rail infrastructure with high flexibility, unfortunately, this software is not available for acquisition or academic research. Simcon provides analysis of infrastructure as a consultancy company.

3.4.8 Planimate

Planimate is a simulation tool produced by the Australian company InterDynamics Pty. Ltd. The tool allows the user to process as a set of discrete events through the use of hierarchical networks. Similar as previous tools, the models are organised into the blocks (entities) according to their roles.

Planimate user interface is similar to Simul8 and Arena. The objects represents entities responsible for hold and transform other entities, for example entry point, exit point, portal, queue.

Items are the entities that circulate into the system, for instance vehicles, signal, material, employees.

Paths can be defined as a sequence of steps. The sequences are usually defined by the modeller for each item class and are represented by arrows connecting the objects.

Interaction happens when the objectives meet the items, the interactions can be described as or as a logic of the system, for instance arrival distribution, rules, priorities.

Within the transport sector Ricci at al (2012) used Planimate to model Port of Messina freight traffic.

3.5 Chapter Conclusions

Table 4 presents the main characteristics of the existing simulation modelling tools in the market and the purpose of the tools.

Table 4:Simulation tools overview

Software	System	Purpose	Advantages	Disadvantages	Stakeholders	Decision level
Simul8	event based	multi-purpose	Flexibility, user friendly	Time consuming to create reliable models	Single	strategic
Arena	event based	multi-purpose	Able to simulate complex models, large used	Time consuming to create reliable models	Single	Strategic
Witness	event based	multi-purpose	user friendly, graphic	Time consuming to create reliable models	Single	Strategic
AnyLogic	Hybrid	multi-purpose	Expansion in Java, Graphic, user friendly, cloud simulations, Rail library, academic version	Require Java	Single	Strategic
OpenTrack	System Dynamics	specific	Reliable model, graphic representation train movements, environmental impact	timetable based	Single	Tactic Operational
Railsys	System Dynamics	specific	Precise	timetable based	Single	Tactic Operational
Villon	Agent based	specific	Freight focused, 3d graphic train movements	time based table	Single	Strategic Tactic
Planimate	Agent based	multi-purpose	User friendly, low cost	less online training material	Singe	Strategic Tactic

With the comparative analysis of the existing simulation modelling tools used for evaluating rail terminals and their main characteristics, the goal was to present the advantages and disadvantages of the existing tools for designing and evaluating rail freight terminals/interchanges. Importantly the multi-stakeholder analysis option is not implemented in the existing simulation modelling tools, suggesting the need for a new features and new package tool development. The development includes an analytical method that provides results for multiple stakeholders (e.g., rail operators, companies managing rail freight interchanges, clients, government). These results will help to provide answers to multi-stakeholder's needs.

Despite the user-friendliness of some simulation software package tools, there is still a barrier to users with no previous experience in simulation modelling or rail operations. For the development of the simulation package, the focus is on the user-friendliness, implementing click and select procedures, similar to the drag and drop system implemented by Simul8, Arena, Witness and Planimate. For the integration of event simulation with agent simulation, which has been proved as a powerful strategy to develop simulations, considering complex scenarios, easy communication with the external software, as implemented by AnyLogic, is an especially useful feature.

The most advanced graphics interface implemented by the simulation modelling tools includes 3d model representation of the train movements (Villon and AnyLogic) and are therefore used in the Interchange modelling tool developed in this work.

The simulation tools developed specifically for rail simulation (Villon, RailSys and Opentrack) focussed on timetable generation and validation through equations in which the time is a fixed variable. For rail freight operations that, potentially can be a disadvantage, considering the improvised operation patterns of most rail freight. Considering the need for multi-stakeholder analysis of the interchanges and the user-friendliness of the existing tools further research will consider the formulation of the Interchange designer tool framework and the development of an integrated instrument.

Chapter 4 : Interchange Designer Framework

Chapter Introduction

This chapter is dedicated to presenting the methods used for developing a software applications framework (Technology Roadmapping, Multi stakeholder Decision methodologies, Analytic Hierarchy Process and Genetic Algorithms). The Chapter also presents the Software main characteristics overview, scope and objectives. The proposed framework aims to identify and combine the main strengths of the methods previously assessed in order to support the development of multi stakeholder simulation tools.

4.1 Decision Making Techniques

The decision making process is a broad topic that has been studied by many disciplines using different approaches and methodologies. The decision making process in rail freight interchanges is influenced by multiple decision makers. In order to develop a tool to support strategic decisions for those decision makers, several elements need to be taken into account, including their behaviour and elements interaction.

The framework developed for the interchange designer tool was inspired by methodologies combining multiple requirements analysis. The Design Rationale Capture Method - IDEF6- proposed by Mayer (Mayer et al. 1995) identifies the problem, constraints, and requirements in multiple scenarios to select a particular design strategy and evaluate the scenario results as illustrated in Figure 49.

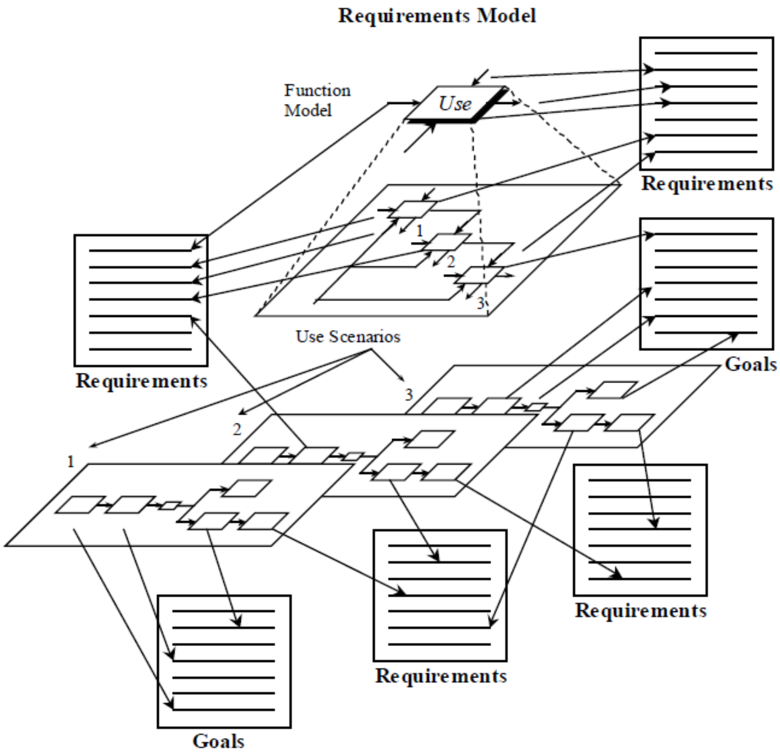


Figure 49: Design Rationale Capture Method – IDEF6 Functions and scenarios mapping to requirements and goals (Mayer et al 1995)

The Recognition-Primed Decision Model (Klein 1989) looks at the decision process with time constraints to generate and evaluate a large set of options quickly.

The model was developed observing how the decisions are made by experienced decision makers. For Klein, the traditional decision models based on the decision-tree framework or option-comparison strategy fail to consider critical aspects of operational settings. The RPD model suggests how the experience of the decision makers can be used to avoid some limitations of the traditional decision-making models. Rather than generating a number of options and then comparing them to each other, the RPD model focuses on the specific situation to evaluate the options through mental simulation and select the first satisfactory solution. Although the RPD model requires extensive experience among decision-makers for complex scenarios (large number of options and time constrained), the model reduces the time required for the decision. Therefore, within the RDP model, the decision maker's inputs in the software package presents an advantage for modelling scenarios with information absences. Figure 50 illustrates the decision making process of the RPD model.

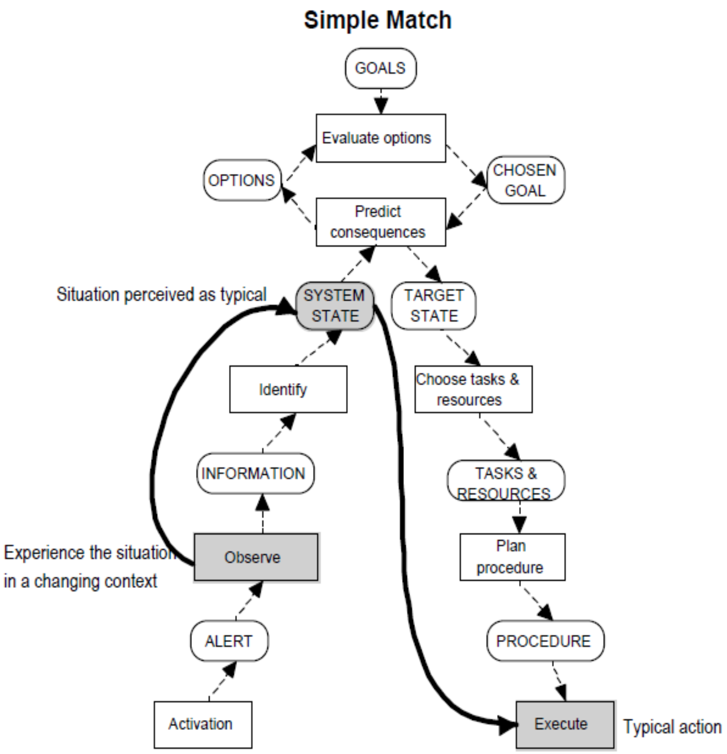


Figure 50: The decision-making process of the Recognition-Primed Decision Model (Klein 1989)

However, despite the advantages of the model for the decision, when the analysis considers multiple stakeholders, a balance between the different preferences is required. As the different players involved would have different needs and requirements, the decision drivers of the stakeholders need to be taken into account. For a new interchange design decision for example Figure 51 the model needs to analyse different decision drivers of each stakeholder, focusing on supporting the decision.

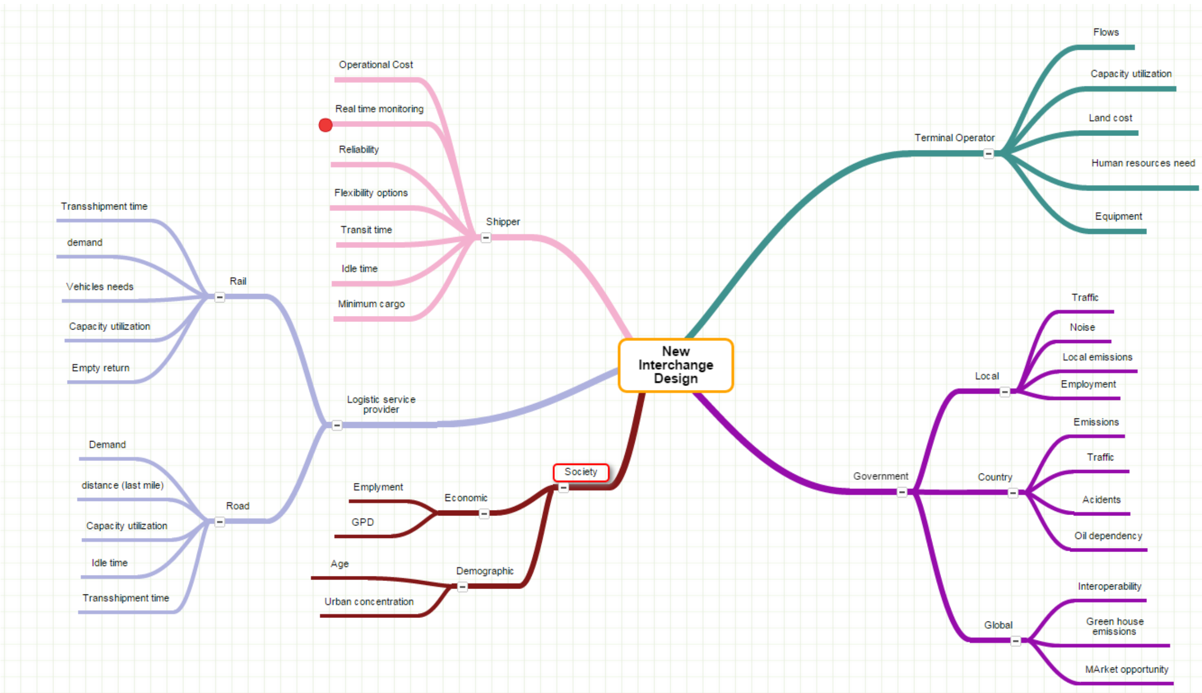


Figure 51: Decision drivers new interchange design involving multiple stakeholders

As the objectives of the different decision makers have different natures, the objective function for the decisions can be conflicting. In table 5, the objective function for the decision makers presented previously have been created.

Table 5: Decision drivers stakeholders and the objective function

Stakeholder/ Input	Decision drivers	Objective function
User / Final client (Performance)	Transport price	minimize
	Inventory cost /transit time	minimize
	Handling price	minimize
	Reliability	maximize
Multimodal logistic operator (Operational cost)	Transport cost	minimize
	Transit time	minimize
	Queuing on terminal	minimize
	Train size	maximize
Terminal Operator (Aquisition cost)	Handling cost/ investment	minimize
	Land use	minimize
	Frquency	maximize
	Train size	minimize
Society (Envoirnmental)	Co2 Emissions	minimize
	Employment generation	maximize
	Traffic	minimize
	Accidents	Minimize

For the user, a higher frequency of trains can increase the reliability of the service. However, for the train operators, fewer but longer trains can reduce the operational costs. The longer trains require bigger terminals to accommodate the longer trains. The software package developed enables the user to weigh the priorities of the multiple stakeholders.

4.2 Technology Roadmaps (TRM)

Technology Roadmapping is a visual methodology that aims to forecast the future market, trends, and future needs to support business strategy planning and product development. Originally developed by Motorola in the 70's, TRM helps predict the impact of future technology driving the industry to identify marketing opportunities. According to roadmapping, purposes can identify 8 main TRM types: product roadmap, services, strategic planning, long-term planning, planning knowledge, program planning, planning processes, and integration planning.

The Technology Roadmap (TRM) is defined by Phaal as a method of management to support technological strategic planning (Phaal et al., 2001b). It helps to provide a visual and descriptive tool that will aim to be the product or project in each period of its evolution. This strategic guideline aligned with multiple stakeholders around the same sequential steps contributes to the planning process, considering the evolution of the market and which variables can be involved

Phaal & Muller (2009) argue the roadmap addresses three main questions (Figure 52):

- Where do we want to go? (Objectives of the roadmap)
- Where are we now? (Current level of technology development)
  - How can we get there? (What technology R & D / policies are required)

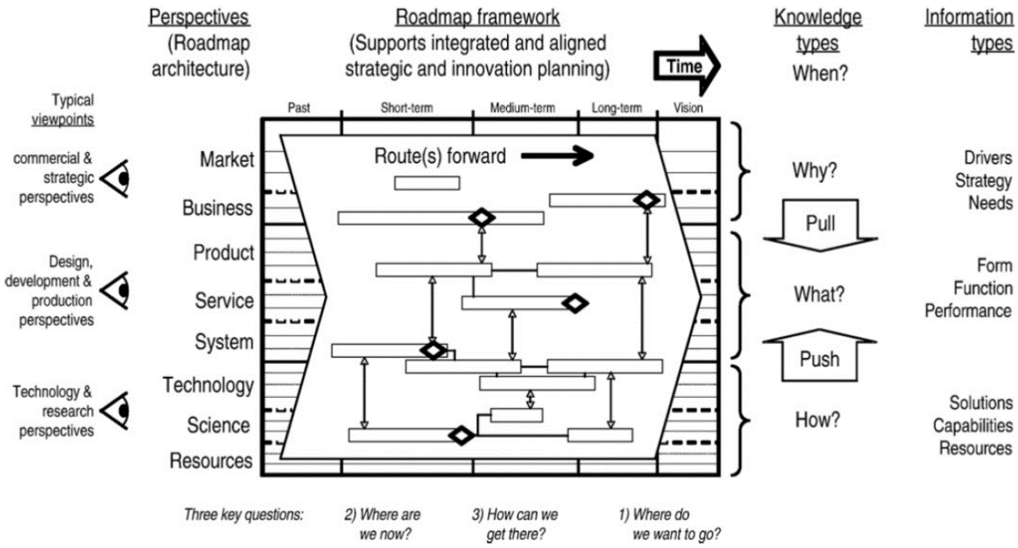


Figure 52: Schematic multi-layered roadmap, aligning strategy provided by Phaal & Muller (2009)

The software package developed in this work uses TRM methodology. Our conceptual TRM model includes 4 horizontal levels and 1 vertical level covering all horizontal levels (Figure 53).

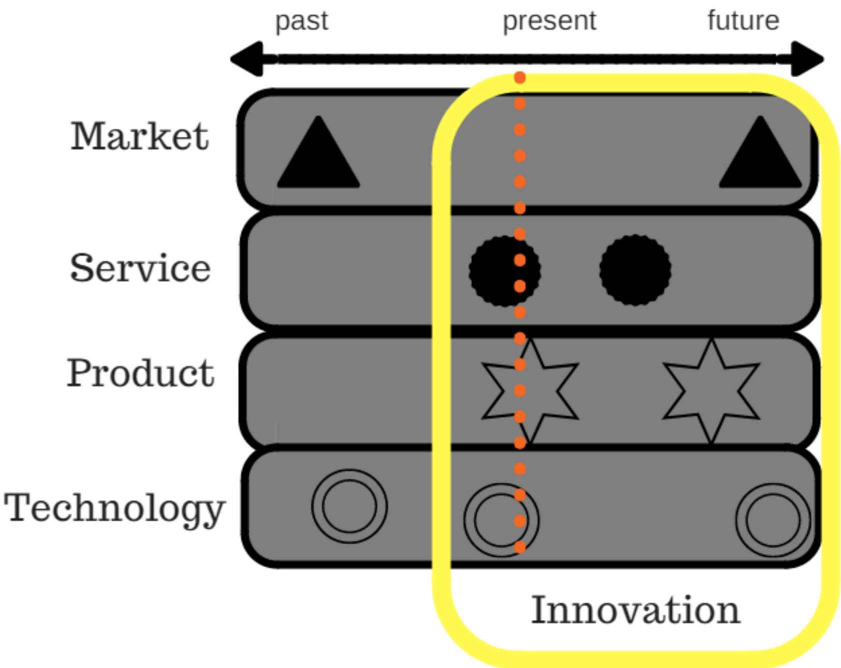


Figure 53: Technology Roadmap used for this research work includes 4 horizontal levels and 1 vertical level covering all horizontal levels

[Market and Business]

The major changes in the freight market and future trends that affect the demand for a certain type of transport [Triangle1] on retrospective analysis and [Triangle2] on prospective analysis. As presented in chapter 1, the type of interchange and the operational requirements are influenced by the changes in the market. Forecasts of the trends on rail market indicate that, by decline of some cargos and the exponential increase of others, changes in the terminals are required to satisfy the needs of different types of cargo. For instance, the decline of the coal transported by rail in UK suggests a potential to redesign coal terminals to receive different cargo.

Table 6: Changes in the market for rail freight

Commodity	Lowest Forecast Growth Rate	Highest Forecast Growth Rate
Coal	-70%	0%
Metals	-20%	20%
Construction Materials	6%	50%
Consumer Goods – Carried Internationally	60%	310%
Consumer Goods – Carried Domestically	200%	1200%
Total Rail Freight	13%	140%

Through the Identification of market changes (table 6) and technological development, we can simulate different terminal handling scenarios to understand the need for each equipment and special development measures. In general terms, longer and heavier trains are more efficient; however, logistic strategies adopted by rail customers, such as just in time, put more emphasis on reliability and speed rather than operational costs. The algorithm is developed to enable the user to introduce different transport demands for analysing the impact of different infrastructure and simulate different interchange designs.

[Service]

Refers to the mode of operation between different types of service terminals as described previously (direct trains, feeder, hub) and the impact of this operation in the interchanges. As presented in Chapter 2, the different operating forms affect the transport demand and commercial requirements and impact the layout of the yard. The software package enables modelling transport productions considering different operating patterns.

[Products]

Products refer to the software package and the integration with the multiple stakeholder decision drivers. Incorporating the Analytic hierarchy process method on the software, each element can be balanced depending on the weight attributed by the user. With the balanced decision driver, the software package can assign a value for each element. The user can change the importance matrix of the decision drivers to evaluate the impact of their preferences on the interchange assistant.

[Technology]

Technology refers to the main technology in the rail industry (T1, T2 and T3). It enables looking at the technological development roadmap to identify and model future developments. Includes modelling the decision as detailed in Chapter 3. Also, introduces artificial Intelligence algorithm for procedural interchange creation (described in Chapter 5).

[Innovation]

Finally, innovation investigates new-generation terminal concepts analyzing, not only the technical aspect, but also economic feasibility for the rail network. In this aspect, the interchange concepts could involve an intelligent system, compact design, and synergetic operations for storage, transshipment, and internal movement. The technology and the role of the interchange need to meet client requirements.

4.3 Software Overview, Scope and Objectives

The software packages in this research work are dedicated to support strategic decision implementation, designing, and supporting decision making for rail/

multimodal planning considering multiple stakeholders' decisions. The software aims to provide easy tools for complex decisions, as well as visualization tools helping to:

- Predict the impact of different equipment;
- Understand the impact of multiple decision drivers;
- Understand the performance of the design/equipment considering different priorities;
- Visualize terminal topology.

The software packages are organized in 4 different packages that can be used in an integrated way or standalone, depending on the need of the user or the scenario to be created.

The first package (DataModule) is based on a Google spreadsheet and deals with input data, such as transport demand, costs, preferences, and efficiency. The package enables balancing the preferences of the multiple stakeholders and can be used to provide outputs for the second and third tools (GaModule and InterDesigning). The GaModule was developed in Java and uses a genetic algorithm for identification of the more suitable equipment for the interchange (multi-objective optimization).

The inputs provided by the DataModule can be introduced in the third tool (InterDesigning) for designing and evaluating the impact of the different equipment/designs. The tool was developed using Unity3d and Objective-C (C#) and 3D models of different infrastructure created using Blender and 3Ds Max (Autodesk).

Finally, the last tool (VR module) was also developed using Unity3D and the 3D models. The tool enables visualizing the infrastructure using VR glasses (Rift / HTC Vive). Depending on the complexity of the design, a simplified version of the terminal potentially can be visualized using smartphones and low-cost VR headsets (e.g., Google cardboard). Figure 54 illustrates the software framework.

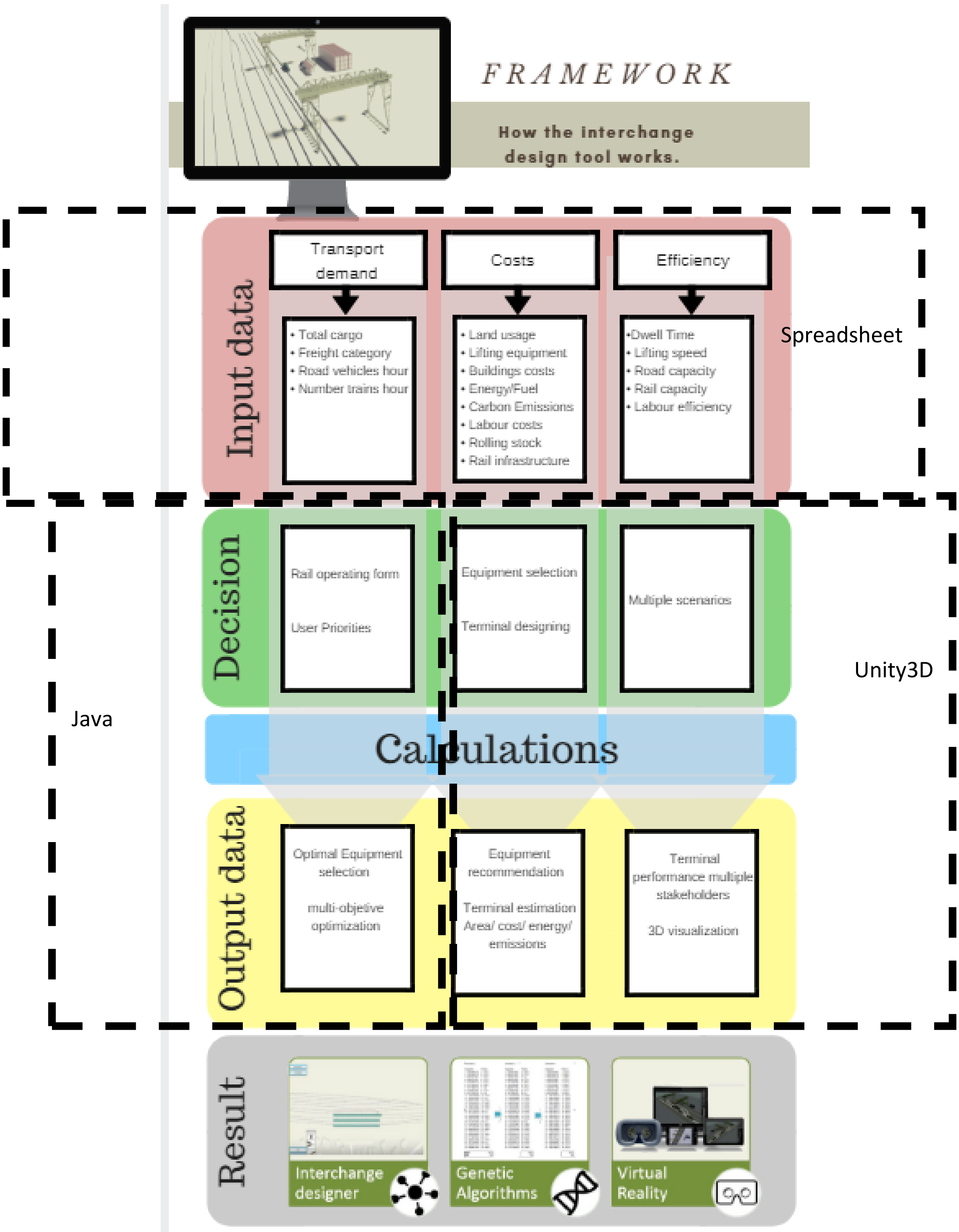


Figure 54: Software package applications framework

Different representation of the simulation process are delivered by each tool results (as illustrated in Figure 54). The Interchange designer tool illustrate the rail freight interchange infrastructure (rail yard and main facilities). The Genetic Algorithm implementation return a number of potential solutions and the higher ranked solution according to individual efficiency and interchange constraints.Virtual reality is the interactive visualization of the terminal, allowing the interchange planner understand the terminal layout.

4.4 Software Packages Framework Development

The use of game engines (Unity3D/CryEngine/Unreal) for modelling and simulating rail infrastructure presents a series of advantages in comparison with the conventional simulation tools presented in the previous chapter. The possibility of developing the software framework with game engines creates flexibility to simulate non-traditional rail infrastructure (this will be explored in the case study 2), new equipment (illustrated in case studie two and three) and enables exporting the model for VR visualization (illustrated in case study three).

In the game industry, the waterfall infrastructure (or Iterative model) is one of the most often used structures. In this method, part of the project is developed in a series of stages of Requirements > Design > Implementation > Verification> Maintenance. For this work, we adopted a variation of the waterfall method for developing the InterDesigning module. Similar to the waterfall, the Agile model includes feedback in all stages of the model (Figure 55).

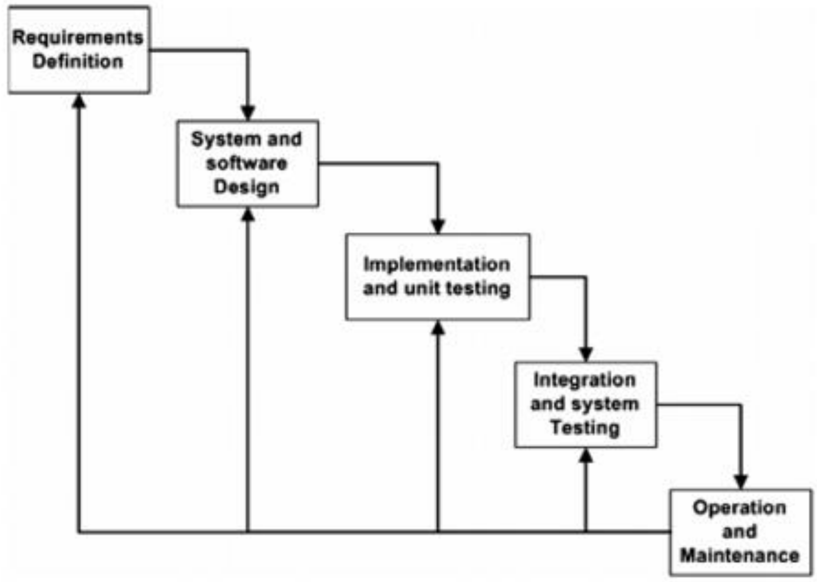


Figure 55: Watterfall model for software develpoment

Although the initial idea was the integration of the 4 tools in one single software package, was decided to maintain the software's independence for the possibility of combining the results of the module and DataModule with the existing simulation packages (e.g., Simul8).

4.5 Software Packages System Architecture

As it can be seen in the proposed system architecture (Figure 56), to take into account the dependence of interchange parameters, the adopted solution is used to evaluate the decision modelling thought spreadsheet. The output of the decision priorities matrix can be used to simulate the evolution process or the interchange design, selecting each section from its construction.

Although the implementation might not find the most optimal solution to the defined problem the Genetic Algorithm allow the user to find a suitable solution in less time considering multiple variables (complex problems). Particularly on rail freight interchanges decisions where limited set of solutions and the typical discrete nature of the design problem (capacity of equipment or storage area) the implementation allow to explore different stakeholders priorities (different efficiency values)

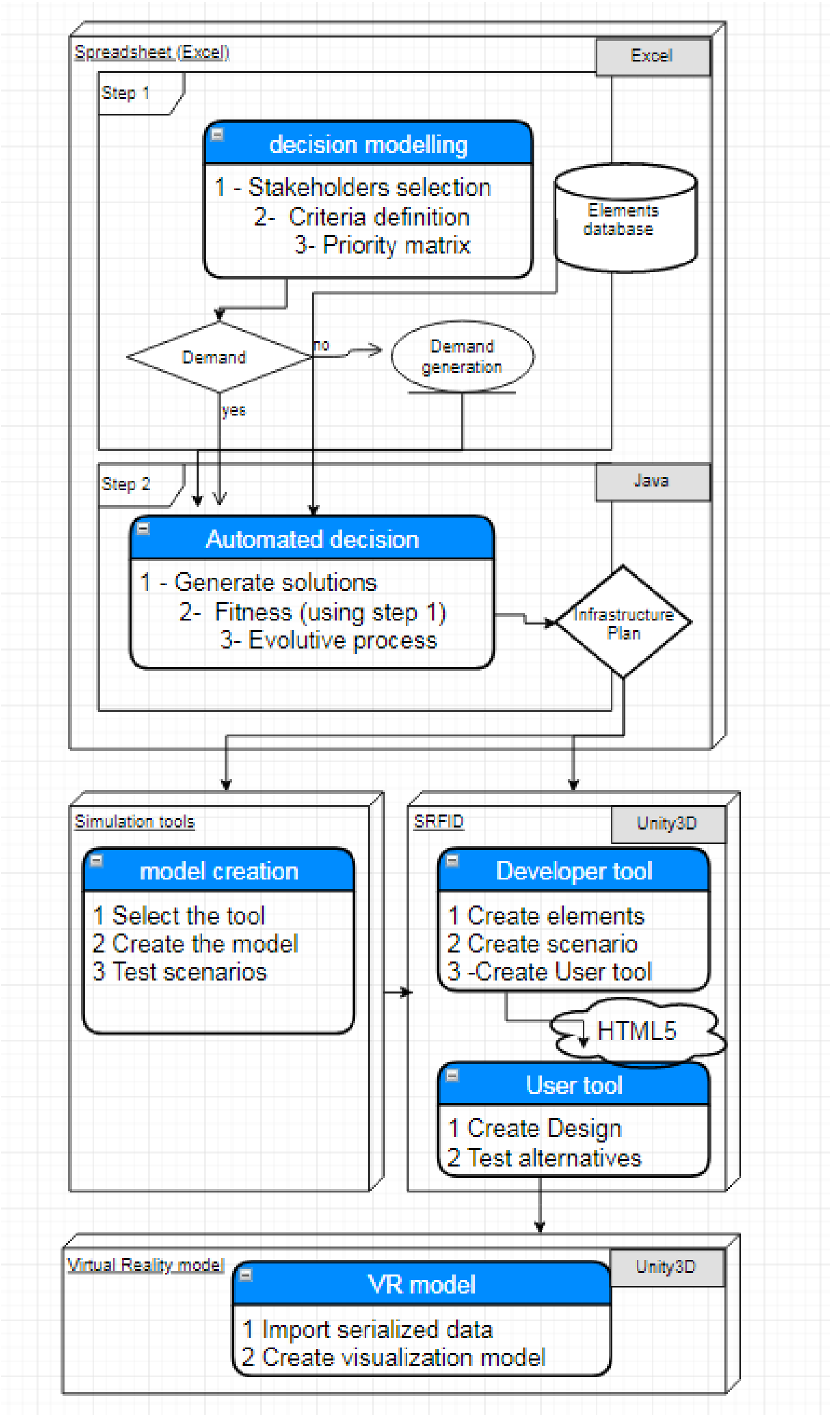


Figure 56: Proposed system architecture

4.6 Multi Objective Hierarchy

Traditionally, decision systems are represented in the form of hierarchical structures. Hierarchies help groups formulate the problem of collective decision-making by giving disproportionate control to a reduced number of members (Van Vugt et al., 2008). The formulation of the decision problem into hierarchical structures allows us to reduce or decompose from system to sub-systems. The software framework developed in this work and adopted in the software packages allows the creation of multiple hierarchical structures (subsystems levels) in equipment, decision drivers, and stakeholders (Figure 57). Depending on the existing data available, the user can model the decision in a greater level of details. It is assumed that the stakeholders involved in the interchange decision are based on multiple characteristics of each selected component of interchange, and the elements depend on this property for the correct behaviour of train movements.

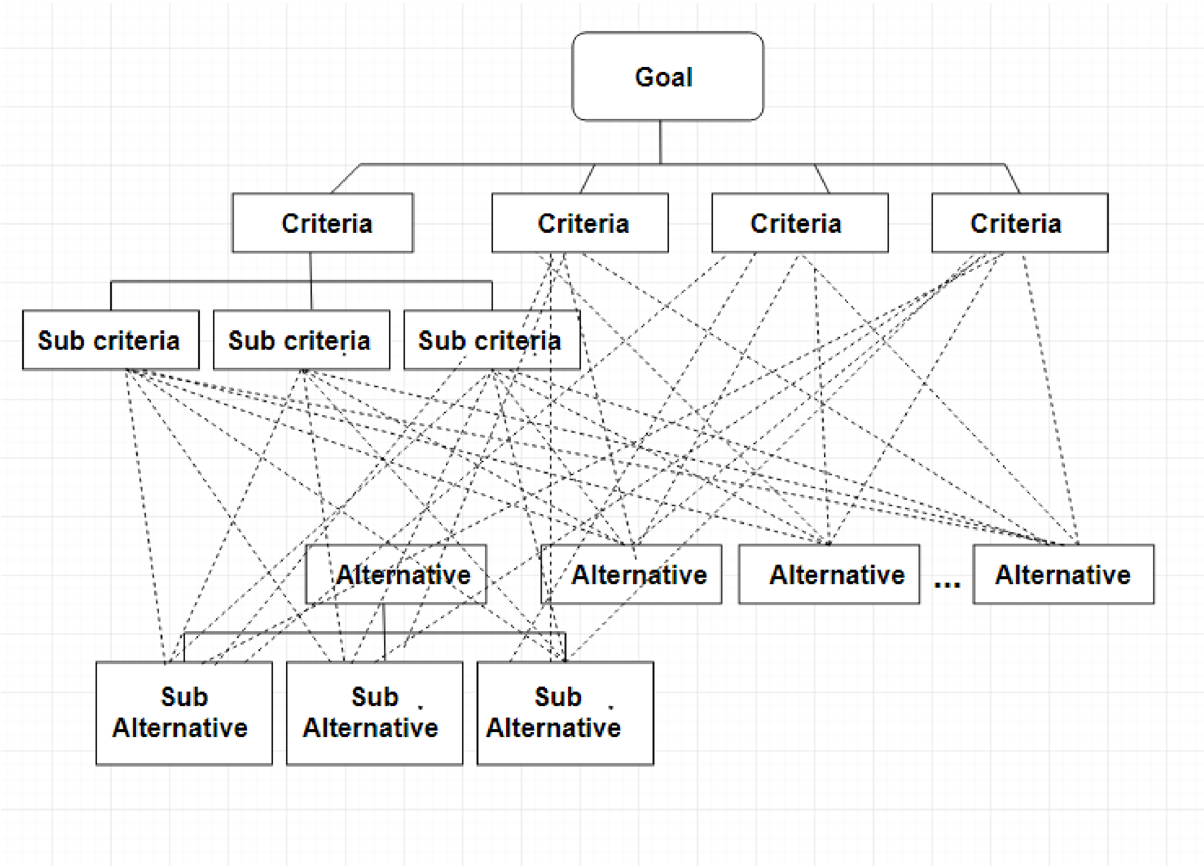


Figure 57: Multicriteria decision scheme showing how the criteria and alternatives are related

4.7 Multi-Stakeholder's Decision-Making Process

The decision-making process in a complex decision often involves multiple stakeholders. In the strategic management area, there is a large amount of literature analysing organizations in terms of a stakeholder model. The embryonic form of a stakeholder's decision can be traced back to Adam Smith; however, modern stakeholder theory from the point of view of organizations is widely attributed to Edward Freeman, who defined a stakeholder in an organization as any group or individual who can affect or is affected by the achievement of the organization's objectives (Freeman 1984). From a narrow view point, Freeman suggests stakeholders might be limited to 'those groups without whose support, the business would cease to be viable.'

Cotterell and Hughes (1995) categorize the different stakeholders in three main categories as shown in Figure 58.

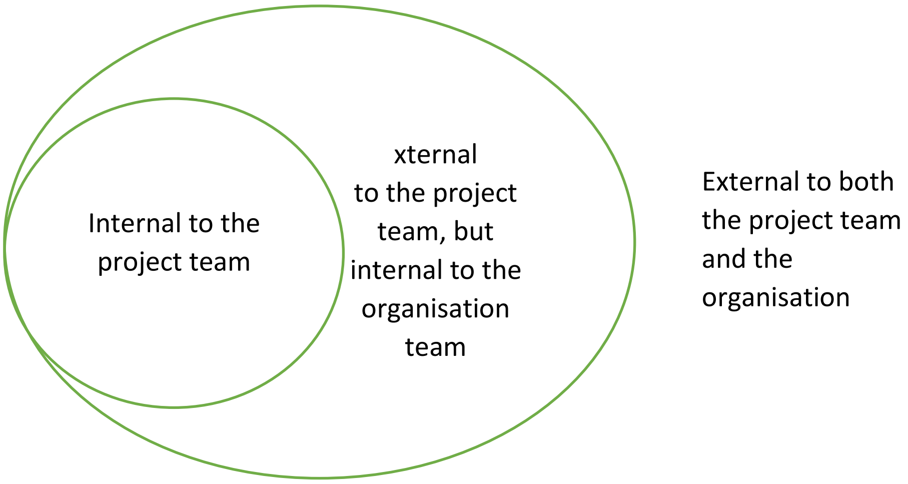


Figure 58: Categories of different stakeholders by their area of influence

The importance of the right stakeholder identification is illustrated by Freeman using several examples of specific stakeholders in large organizations, showing how useful it is to identify with much greater specificity than is presented traditionally in theoretical discussions.

For example, in the case of a Government water supplier, a stakeholder map might be drawn in which customers could be separated as residential customers with low water consumption, residential customers with very high consumption, residential customers with modest incomes, industrial customers etc. The government relationship can be broken down to include government owners, responsible department, relevant regulators, relevant tax offices etc.

Christopher and Lee (2004) mentioned the role of suppliers in the resilience to supply chains, stressing the necessities of a collaborative relationship between the suppliers. According to the researchers, risk mitigation is possible through suppliers with high visibility.

Specifically, for the interchanges, the SRFI Policy Guidance (DfT2011) considers three main dimensions: economic, environmental, and social. David and Marinov (2016) analysed the impacts of new interchanges and required equipment to consider 4 main stakeholders in an interchange decision: Client, Multimodal operator, Terminal Operator and Society.

There are many practical domains where decision making that guarantees the goal of satisfaction of multiple stakeholders is difficult to achieve due to a very large number of decision drivers and uncertain effects. Nevertheless, the decision-making process and the role of stakeholders is gaining attention. Multiple-criteria decision analysis (MCDA) methodological process has been developed to build a multi-criteria evaluation to support decisions considering multiple stakeholder strategy thought sensitivity analysis.

4.8 The Analytic Hierarchy Process (AHP)

Highly complex problems usually present characteristics that require experience and intuition by multiple decision makers, such as dynamism, uncertainty, the existence of multiple scenarios, multiple criteria (usually in conflict). The analytic hierarchy process (AHP) is a multiple-criteria decision method aiming to fulfill the need to incorporate the experience of the different decision makers s in the resolution of the problem, harmonizing the different perceptions of the reality of the actors involved in the decision-making process, with their particular decision drivers (economic, environmental, cultural, aesthetic, social etc.).

The method was developed originally in the mid-1970s by Thomas Saaty, dealing with complex problems from the view point of multiple concurrent criteria. The AHP method has been used for a wide variety of decision making processes, in fields such as government, business, industry, healthcare, and education (Boroushaki and Malczewski, 2008; Forman and Gass, 2001; Jyrki et al., 2008; Linkov et al., 2007; Raharjo et al., 2009 ; Saaty, 2008).

According to AHP formulation (Saaty 1996): The AHP should be (a) simple in its construction; (B) adaptable to individual and group decisions; (C) in line with our judgment, values, and intuitions; (D) focused on the search for consensus, and (e) does not require high grade of specialization for its application.

The basic principle of AHP is that a decision-making problem can be structured hierarchically, where the top of the hierarchy contains the general description and at the levels below are the criteria (or Attributes) that are taken into account for the approach. Those criteria may be successively subdivided into sub-criteria . At the last level of the hierarchical structure are the alternatives considered in the analysis. The meaning of the positioning of alternatives is that each of these alternatives will be analysed individually, under these sub-criteria (or criteria). Figure 59 illustrates the traditional AHP process with an example of the Hierarchical structure.

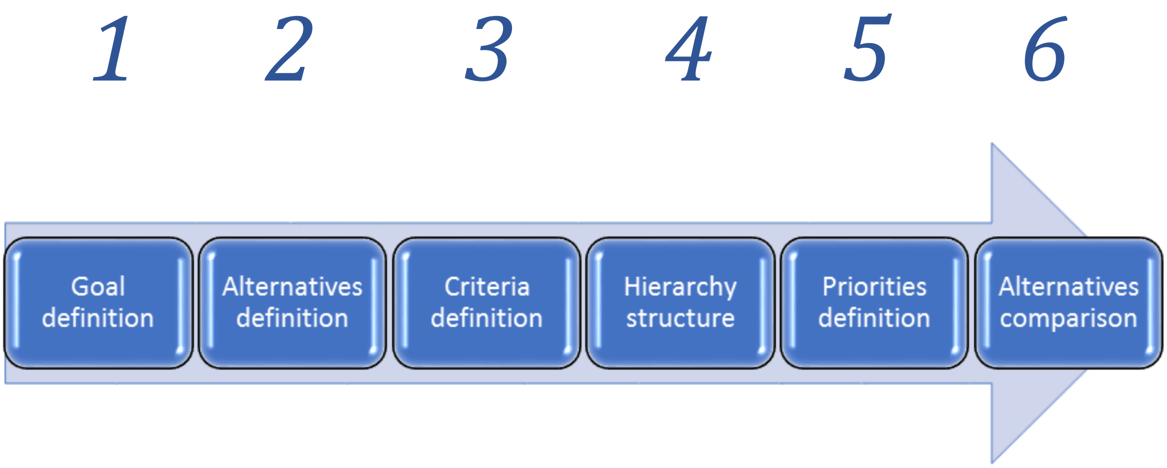


Figure 59: Six steps for the AHP method

After defining the hierarchical structure for the decision problem, the next step is the assignment of relative values for the criteria. The purpose of this step is to define the importance of all criteria. According to Saaty (2001), experts are able to divide qualitatively their responses to a stimulus in three broad categories: high, medium, and low, refining these divisions again in high, medium, and low, generating nine subdivisions for the intensity of importance (Reason Range or Basic Scale of Saaty). To set these values, Saaty suggests several parities (or paired), where the criteria are compared between two to two with the intensity of importance. Those judgments are stored in a square matrix (reciprocal and positive) n x n, called pairwise matrix or dominant matrix comparisons. The elements of this matrix containing the values from the peer-to-peer comparisons express as the number of times one alternative dominates or is dominated by the others. Each element next to the vector of the dominant matrix represents the dominance of the alternative Ai (Line) over the alternative Aj (from the column).

The main diagonal of the decision matrix is filled with a value stipulated to represent the non-dominance of one alternative over the other (in fundamental scale this corresponds to value 1). If the element Ai is more important than the Aj element, some value from 2 to 9 is inserted. If Ai is less important than Aj, a number inverse to the values of 2 to 9 is inserted, 1/2, 1/3, and so on. In square matrices, Aij, for i = 1,2, ..., n and j = 1,2, ..., n. Such matrices are also called reciprocal and positive (aij = 1 / aji). The total calculation of judgments for the composition of the comparison matrix is represented by n (n-1) / 2, equal to the number of the decisions.

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} \cdots & \frac{w_1}{w_n} \\ \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} \cdots & \frac{w_n}{w_n} \end{bmatrix}$$

For wi, the relative weight of criterion is i. In this case, the relative weights may be easily obtained from any of the n lines of A because Aw = nw for w = (W1, w2, ..., wn). In linear algebra, n and w are respectively called eigenvalue and right eigenvector of matrix A. The AHP considers the decision that constructs the matrix of comparison between the pairs does not know w. As Matrix A contains inconsistencies, it is necessary, therefore, to determine a measure of acceptable consistency for the method. In order to understand the eigenvector method, a conceptual approach on one of the pillars of the AHP method is necessary.

4.8.1 The importance of Proportionality and Standard Scales for the Analytic Hierarchy Process..

The step of measuring is key in the AHP, notably measurement on a ratio scale. Decision weights and priorities are acquired from the stakeholder's evaluations of the way in which each alternative of a decision problem compares with respect to all alternatives at the same hierarchy level.

Ratio scales are used to generalize a decision because they can be added and multiplied when they belong to the same scale, as priority scale. When two decision-makers reach different scales of the reason for the same problem, one must test the compatibility of the responses of both and accept or reject "closeness" between them. Therefore, with the ratio scales, one can associate each alternative with a vector of benefits, costs, opportunities, and risks to determine the most suitable alternative to the problem. In AHP, the relative ratio scale derives from the matrix of judgments reciprocal to the comparison of the alternatives, two by two (peer-to-peer), resulting in the following system:

$$\sum_{j=1}^{n} a_{ij} w_{j= \lambda_{max} |} w_i$$

$$\sum_{i=1}^{n} w_{j=1}$$

Where:

a_{ij} = 1 / a_{ij} or $a_{ij}a_{ji}$ = 1 (reciprocal property), a_{ij}> 0 (A is positive matrix), whose solution, known as the right eigenvector, is normalized in (2). A relative value scale does not need a unit of measure;

w_i: eigenvector;

λ_{max} : eigenvalue; and

A: matrix of judgments *n* x *n* of *i* rows and *j* columns, with *i* and *j* = 1,2, ..., n.

When $a_{ij}a_{jk}$ = a_{ik}, the matrix *A* = (a_{ij}) is called consistent and its principal eigenvalue equals *n*. Otherwise, the matrix is only reciprocal. The general formulation of the eigenvalue shown is obtained by following system:

$$A_1 \quad A_2 \; ... \; A_n$$

$$\text{Aw} = \quad A_1 \; \vdots \; A_n \quad \left[\frac{w_1}{w_1} \; \frac{w_1}{w_2} ... \; \frac{w_1}{w_n} \; \vdots \ddots \vdots \; \frac{w_n}{w_1} \; \frac{w_n}{w_2} \cdots \; \frac{w_n}{w_n}\right] [w_1 \; \vdots \; w_n] = n[w_1 \; \vdots \; w_n] = nw$$

After defining the goal to be achieved and criteria that will be used, the analysis of the problem can be done in several ways. One of the most common is consulting on specific aspects with specialists in particular subjects that will evaluate your area with more ownership (buy in). For our example, in a problem of selecting the most suitable design for a rail freight interchange, technical aspects will be well-evaluated by engineers who know the subject. Financial aspects will be well-evaluated by people who know the subject and analyse the market to quantify projections of future revenues and associated investments. Only then will it be possible to define its economic viability.

Despite the success of the AHP in different fields, some particularities of the method have been contested by a number of academics. Barzilai (1998) argued that the traditional AHP mathematical framework is limited to linear value functions, potentially contributing to incorrect hierarchical decomposition. For Koczkodaj and Szwarc (2013), the consistency index tolerance is incorrect, tolerating approximation error of an arbitrarily high-value rank reversal phenomenon. Adding an irrelevant alternative may cause a reversal in the ranking at the top. Fulop et al. (2010) suggested the scale for pairwise comparisons as the biggest problem for practical applications, proposing using smaller scales to improve the traditional pairwise scale. Perez et al. (2006) analysed the impact of the introduction in different criteria (all alternatives perform equally), showing a significant alteration of the aggregated priorities of alternatives potentially resulting in formal failure.

4.8.2 AHP in the DataModule

Multiple factors impact the transport demand and capacity, influencing the interchange utilization at all levels. Therefore, interchange planning is a step-wise, sequential process, where later steps are heavily dependent on earlier ones. As the main vertical arrow in Figure 60 indicates, the interchange planning is focused on the strategic and tactical levels.

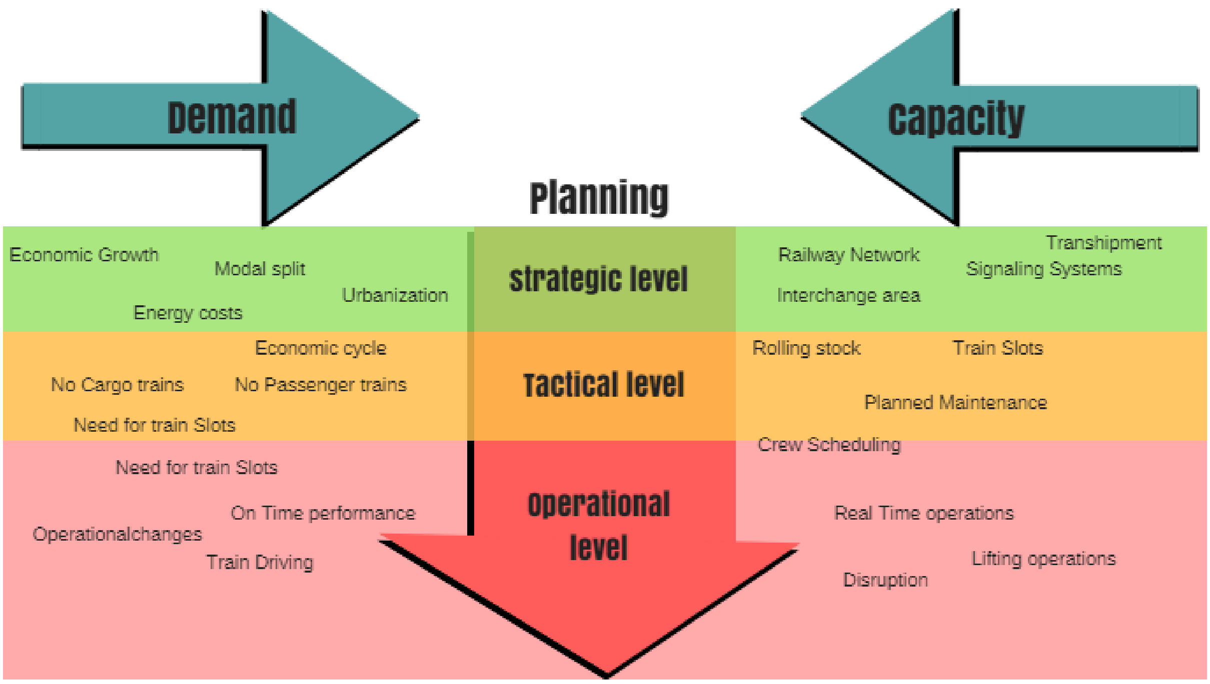


Figure 60: Decision levels Interchange planning

Based on capacity utilization, the need for new decision support tools for planning interchanges on various levels is evident. Figure 61 summarized the decision requirements in a schematic way. Unlike the one-directed planning progression (strategic > tactical > operational) the representation includes backward arcs representing a feedback of information to a previous planning stage. These connections are of special interest when planning interchanges considering multiple stakeholders.

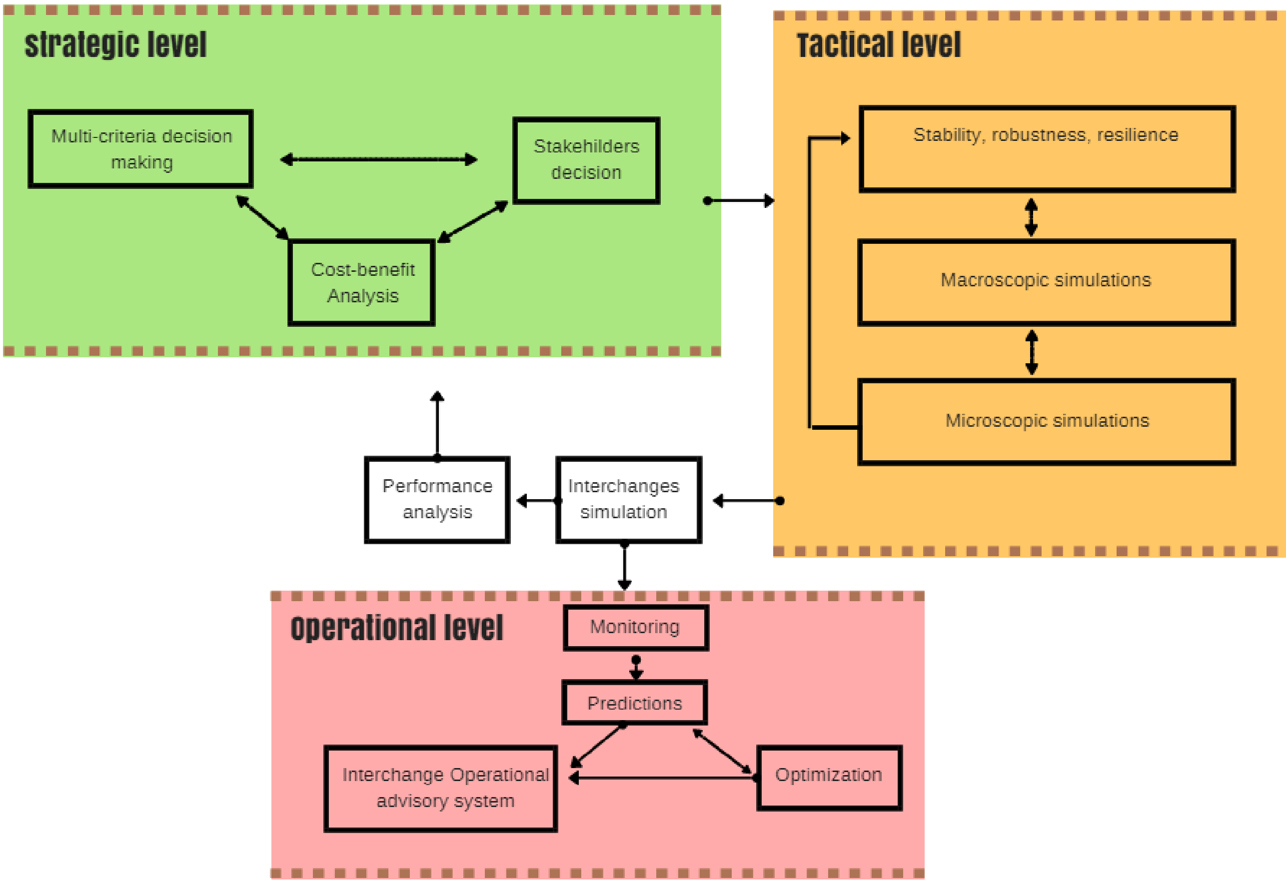


Figure 61: Decision levels and influence

4.8.3 Implementation of Framework

The implementation of the Analytic Hierarchy Process (AHP) method in the software aims to create a measure system for priorities among criteria and alternatives to be used in a second stage as a fitness function of the genetic algorithm.

An online spreadsheet (google spreadsheet) was used to implement the AHP method to use the data as input for the SRFID. The spreadsheet is avaliable at : https://goo.gl/cT5zZV

As it can be seen in Figure 62, the user selects the priority in the drop menu.

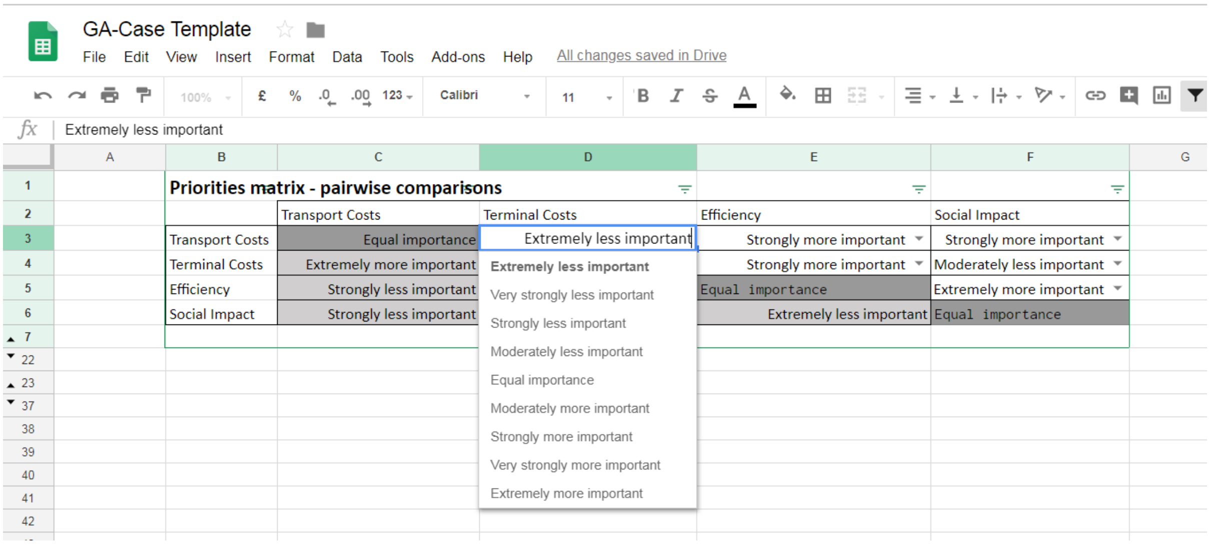
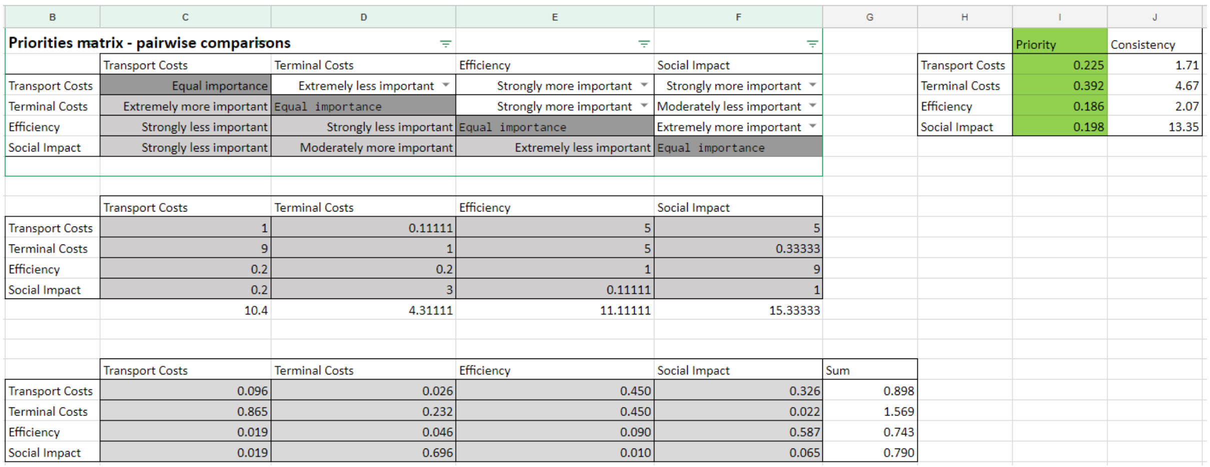


Figure 62:Spreadsheet input priority AHP implementation

After selecting the drop-down menu, the table automatically fills with numeric values for the calculation of the priorities. The calculation of the diagonal of the decision (normalized resulting matrix) is calculated based on the decision as well the balanced priority and consistency test (Figure 63).



Priorities matrix - pairwise comparisons

	Transport Costs	Terminal Costs	Efficiency	Social Impact
Transport Costs	Equal importance	Extremely less important	Strongly more important	Strongly more important
Terminal Costs	Extremely more important	Equal importance	Strongly more important	Moderately less important
Efficiency	Strongly less important	Strongly less important	Equal importance	Extremely more important
Social Impact	Strongly less important	Moderately more important	Extremely less important	Equal importance

	Priority	Consistency
Transport Costs	0.225	1.71
Terminal Costs	0.392	4.67
Efficiency	0.186	2.07
Social Impact	0.198	13.35

	Transport Costs	Terminal Costs	Efficiency	Social Impact
Transport Costs	1	0.11111	5	5
Terminal Costs	9	1	5	0.33333
Efficiency	0.2	0.2	1	9
Social Impact	0.2	3	0.11111	1
	10.4	4.31111	11.11111	15.33333

	Transport Costs	Terminal Costs	Efficiency	Social Impact	Sum
Transport Costs	0.096	0.026	0.450	0.326	0.898
Terminal Costs	0.865	0.232	0.450	0.022	1.569
Efficiency	0.019	0.046	0.090	0.587	0.743
Social Impact	0.019	0.696	0.010	0.065	0.790

Figure 63: Calculated values. Example based on the user priorities

The multi-objective implementation developed looks to reduce the decisions in two main categories of efficiency (where the objective function tries to maximize) and constraints representing the limits of the algorithm.

4.9 Evolution programming and Genetic Algorithm (GA)

The Evolutionary Computing (EC) was developed by Holland (1970) in the early 1970s, but the best literature source for genetic search could be found in Goldberg (1989) and Koza (1992). This field of computing science simulates the biological evolution process on computers to identify and compare a set of solutions toward better overall solutions. The Genetic Algorithm (GA) is one of the main fields of the evolutionary computation. The other variants of Evolutionary Algorithms are Genetic Programming (GP), Evolutionary Programming (EP), and Evolution Strategies (ES).

Genetic Algorithms can be categorized as global search heuristics. It involves the evolution of a population of individuals representing possible solutions to optimization problems. In GA, each individual is normally described by a string of symbols. The concept is inspired by genetic code (DNA). The search process on GA is made by an iterative application of genetic operators, for example, crossover, mutation, and natural selection operators by the fittest individuals. The population of solutions evolves until the stop criteria are reached.

The Genetic Algorithms methodology has been applied in numerous problems where classical methods of optimization and designing methods were not able to produce an adequate solution in a reasonable computation time.

The main advantage of the genetic algorithms applied to interchange design is to simplify a complex optimization problem, especially for conflicting stakeholder requirements. Using a set of inputs and user-defined constraints, the algorithm searches and ranks adequate solutions for an optimization problem.

Initial concepts used in GA:

- Chromosomes/individuals: Represent a particular solution to the problem to which the genetic algorithm has been applied. Includes a set of parameters divided into genes.

- Gene: Representing a sub-selection of chromosomes (possible candidates of solution) in a string. In the software package, the number of genes is the number of the items that can be selected for the interchange.

- Population: Refers to the initial number of candidate solutions to be generated. The user can determine the size of the initial population to be generated by the software.

- Generations and Evolution: Generations are formed though evolution steps where the parents' chromosomes are modified, generating offspring/children. These offspring chromosomes became a new population replacing some of the chromosomes in the previous generation. The user can define a specific generation limit for the evolution or wait for the stop criteria (implemented on the package as three generations without changes).

4.9.1 Gene Representation for Genetic Algorithm

Generally, chromosomes are encodings as binary strings and tree encodings. The binary strings can decode in a single gene or comprehend multiples genes.

The representation of the solution can be encoded in a single gene where each alternative is represented in each gene or represented by a number of genes where each alternative is represented by a specific series of genes. Figure 65 exemplify the process considering five gene representations.

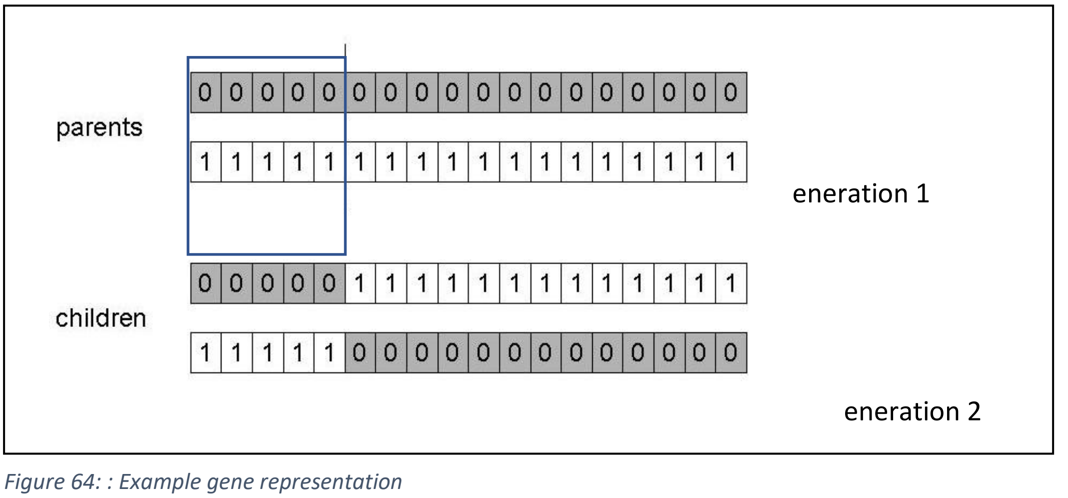


Figure 64: : Example gene representation

The multiple gene representation helps to create solution in shorter genes, however a indicative table are required to translate the gene representation into the elements. For our GA algorithm model, each gene represents one element, and the number 1 in the gene represents that the element I exists in the individual solution (chromosome). The 0 indicates the absence of the element.

Random numbers package is used to create the initial population (Java) as shown in Figure 65. The software was developed to enable the user to create a high number of initial populations (>10000).

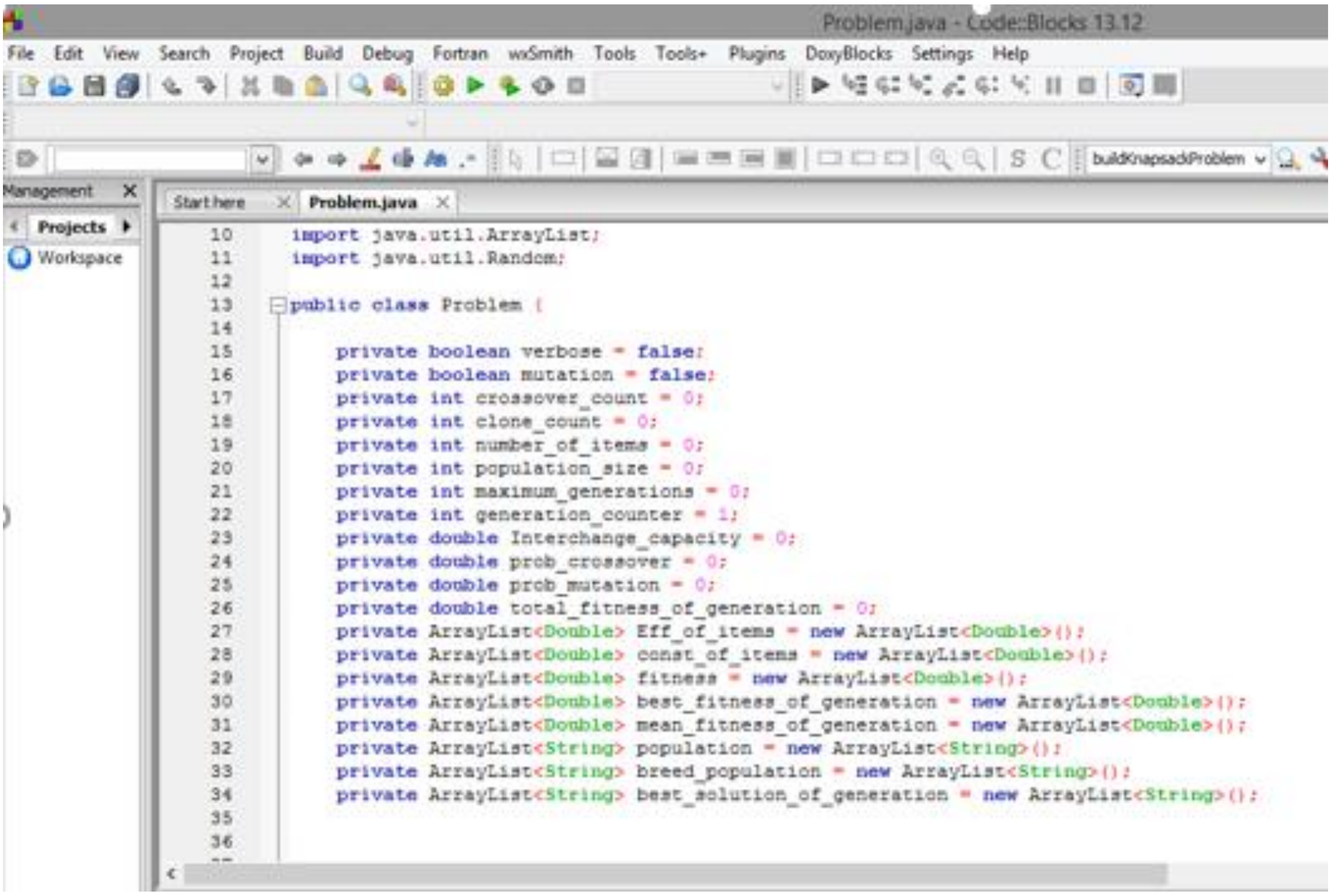


Figure 65: Main variables for the Java script

4.9.2 Genetic Algorithm Evolutive Process

In the evolution stage, the algorithm compares the offspring chromosomes to identify the solutions against the fitness criteria. The replacement of the genes though values defined by the user for crossing over rate or mutation are the base class for the parameters of replacement operations. This rate defines the % of chromosomes that should be replaced.

In the GA method, the mutation usually is performed after crossover operation to prevent putting all solutions into a local optimum of the solved problem. Mutation modifies new offspring by changing genetic bits (e.g. 1 to 0) as illustrated previously by Figure 65.

The java application was developed to run through command prompt (MS-DOS) using the line command :

C:\foldername\java inter/Problem [simulation name]

By the end of the process, a text report is generated and another JavaScript creates a graph illustrating the average fitness evolution created.

Figure 67 describes the main elements of the GA and step by step of a typical genetic algorithm. A population of individuals is generated randomly and if the termination criteria (which could be defined by the user) are not met, the solutions will be evaluated based on the fitness criteria and be combined to generate future generations. During the process, each generation is combined with a new population of solutions using genetic operators (crossover, mutation, or inversion). A case study will focus on the crossover process to find the equipment decision solutions.

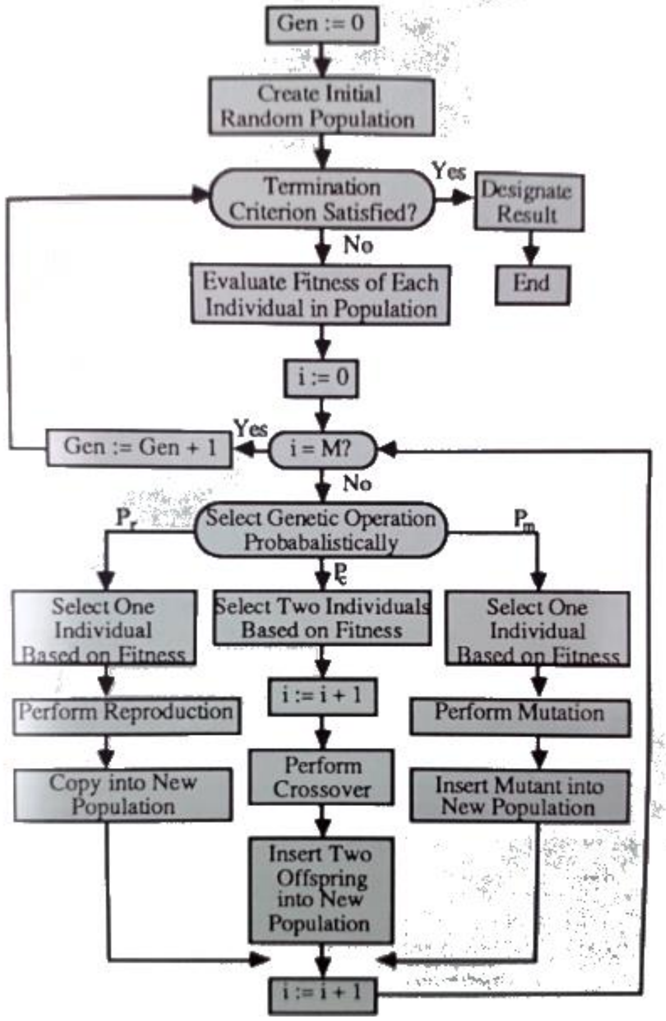


Figure 66: Genetic algorithm process (Koza 1992)

4.10 Chapter Conclusions

This chapter presented the software applications framework and the tosoftware packages developes (DataModule GaModule and InterDesigning) discussing how Technology Roadmapping, Multi stakeholder Decision methodologies, Analytic Hierarchy Process and Genetic Algorithms were combined to support the decision making process in rail freight interchange strategic planning.

Chapter 5: Software Implementation for the Interchange Design Tool

Chapter Introduction

In this chapter, we present the software framework used for the InterDesigning tool. The main focus of the chapter is to provide a description of the components and demonstrate how different methods and tools developed are combined to support the interchange decision. The research question in this chapter is: "How can we improve the simulation tools integrating new methods and features for designing rail freight interchanges?"

5.1 Game Engine as a Tool for Software Development.

The term "game engine" was popularized in the mid-1990s 3D first-person shooter games, such as Doom and Quake. The use of computer game technology for non-entertainment has gained a significant interest of researchers over the last decade with a growing interest in academia, especially around the potential of game engines for game-based learning and education; however, the scientific use of game engines in the field of transport engineering has received relatively little attention by researchers.

Game engines can be broadly defined as middleware, software that allows interaction of other software, enabling software developers to focus on the core application. Game engines provide the main framework and coherent interface to the different functionalities for developing games with a wide range of reusable components, such as saving/loading systems, animation controller, collision detection system, physics, external inputs/outputs, artificial intelligence. Lewis and Jacobson define game engines [Lewis and Jacobson 2002] as a “collection of modules of simulation code that do not directly specify the game’s behaviour (game logic) or game’s environment (level data)”. The possibility to reuse elements and the server storage (web version) enabling level editing is especially useful for the purpose of this research work. In addition, multi-platform output reduces significantly the risk of hardware incompatibility/error. The use of Game Engine in this work allow represent rail infrastructure and rail yard process in a simplified representation of functional components of terminals.

Generally, developing software applications through game engines, the developer needs to connect the game code (responsible for game mechanics/ parameters/ agent behaviours) with other components. The rendering of the game is processed by the engine connecting the network code and graphics drivers, which is responsible for translating the protocol in software for the operating system of the computer. Depending on the software, a local version of the application can be developed for installation on the computer or server development (HTTML5) for online application. The server application enables independent processing, usually on server machines, maintaining information on the cloud and enabling multiple users and shared information/ environments (multiplayer) (Figure 67).

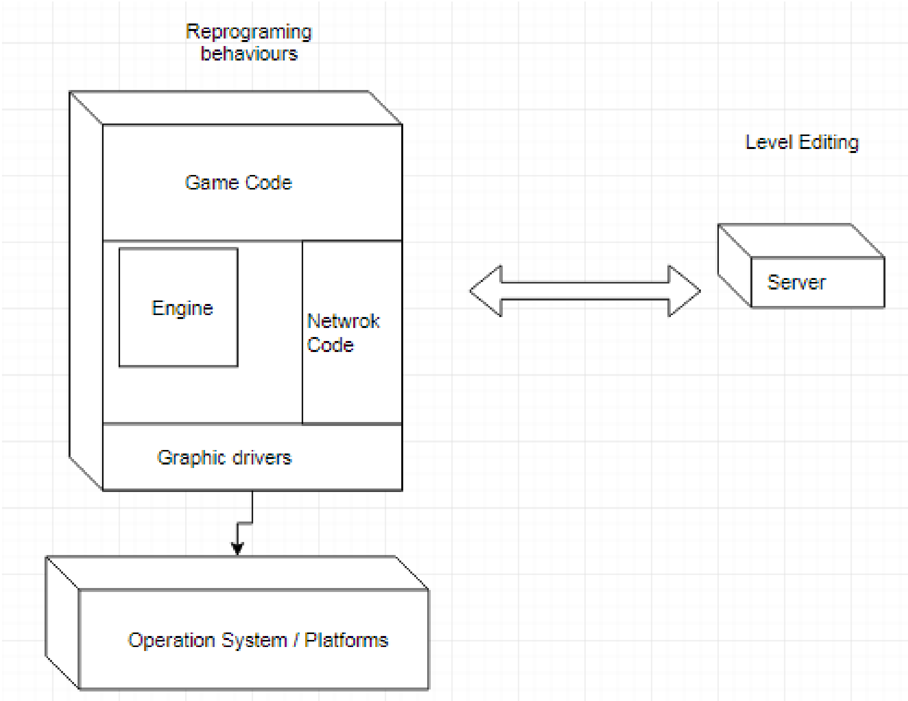


Figure 67: Game engine components

For the development of this work, three of the most used game engines were considered. Table 7 shows some characteristics of the game engines.

Table 7: Game engines characteristics

Engine Name	Notable titles	Release Year	Target Platforms	Lighting
Unreal Engine	Gears of wars, Mass Effect, Bioshock	1998	X Box, Playstation, Windows, Oculus Rift, Smartphone (IOs, Android)	Dynamic lighting and shadow, HDR (High Dynamic Range) Rendering
Unity	Assassins Creed PokemonGo	2005	X Box, PlayStation, Windows, Oculus Rift, Smartphone (IOs, Android),Online HTTML5	Dynamic lighting and shadow, HDR (High Dynamic Range) Rendering
CryEngine	Far Cry Crysis	2002	X Box One, PS4 Windows, iOS, Android	Dynamic lighting and shadow, Time of day lighting

Unity or Unity3D is the most used game engine for independent game developers and small teams. It enables separation of game-specific rules and data (collision detection and game entity). In comparison with the other game engines, Unity3D has more online documentation and support. It is compatible with the programming languages JavaScript and C, #Unity also is able to import several 3D extensions. Depending on the hardware configurations, it may crash quite often, especially the scripting system Mono develop, which is an open-source implementation of the .NET Framework.

CryEngine – Of the analysed game engines, Cry is the more graphically powerful. With the optimized volumetric cloud system (especially useful for Virtual Reality), Cry gives clouds full 3D spatial rendering space and is capable of doing more environment light and shadows for complex light effects. The engine gives full source code access to the developer and is free of charge. However, the complexity in pipelines (importing assets, models etc.) makes the Cry engine more suitable for experienced game developers or those with focus on first-person shooter games.

Unreal Engine: Also has good graphical capabilities. The template system of different game genres is helpful for beginners to understand the basic elements of the engine. Like Cry, it allows the developer to use visual scripting (graphical representation of the code) called blueprint in unreal Flowchart in Cry. Figure 68 illustrates an example of the visual script.

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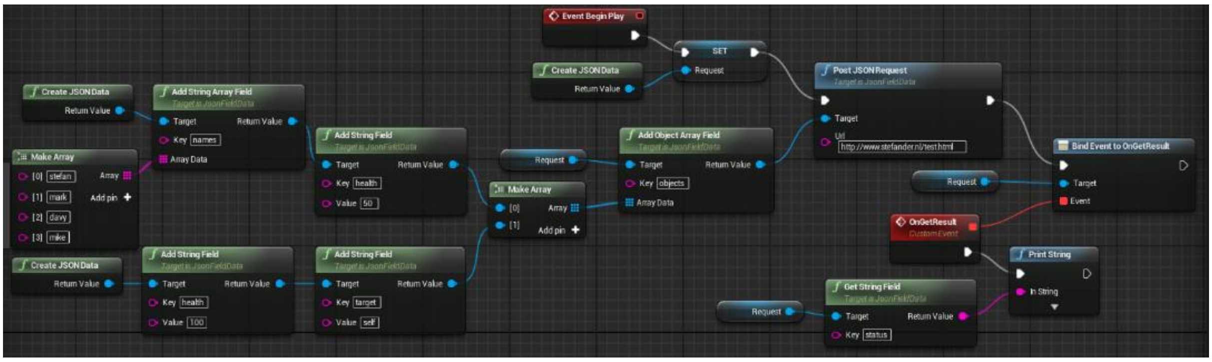


Figure 68: Unreal visual scripting

After testing the three game engines, the Unity3d was selected because of the integration with HTM5 and for the online support provided by the Unity community. The integration with Blender (open source 3D modelling tools) also was an important factor in the decision.

5.2 Unity 3D Basics Development

This section provides the basic understanding of the software main sections to enable the unfamiliar readers to understand the main components (game objects in unity) and Unity workflow, the development of the algorithms (scripts), and the interrelation between scripts, and finally, the compilation of the Interchange framework.

Therefore, before presenting the scenario creation tool and the interchange designing application, Unity interface and basic folders is first present the (Figure 70).

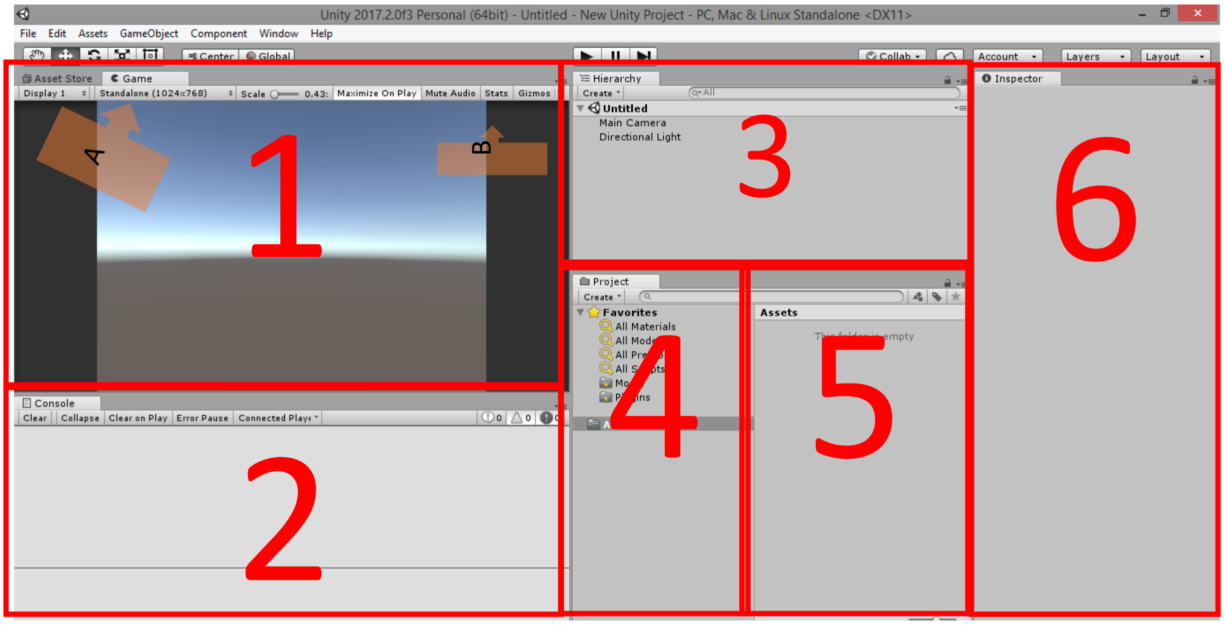


Figure 69: Unity user Interface (default)

1 Game/Scene: This area provides a graphical representation of the game elements and is where all visual components can be placed in the Unity environment. It enables a preview of the game in real-time and tests game performance. In Figure 70 Clicking on the button signalled by the arrow A, the user can change screen configurations in the previewing mode of the application. By clicking on the button signalled by the arrow B, the user can see the stats of the application. Depending on the number of elements and the graphics quality, the CPU consumption can dramatically reduce the frame rate and potentially crash the application in devices with lower capacity. This feature is particularly important for online applications and apps to target mobile devices (iOS and Android).

2- Console: This section presents potential errors in the code, such as missing scripts, game objects. Also, it shows messages coded by the user to test the code (debug function).

3-Hierarchy: This is the most important area of the interface. It lists all the objects in the scene and all children the components may have. Children are game objects directly subordinate to the parent object. It follows the changes to this parent object.

4- Project- This zone presents the organization of the project into the folders. It helps to maintain the different assets separated according to the function (scripts, 3d models, sound).

5 -Assets view: This is a list of assets available in the project for our application, including game prefabs (pre-assembled and game objects). The use of prefabs saves memory and improves the performance of the software. In the following sections, prefab creation for the application is presented.

5. Inspector: This section presents the characteristics and the components attached to a particular game component. For example, by clicking on the camera component, the camera component is shows (Figure 70). By clicking on the Directional Light, it shows the light components (Figure 71).

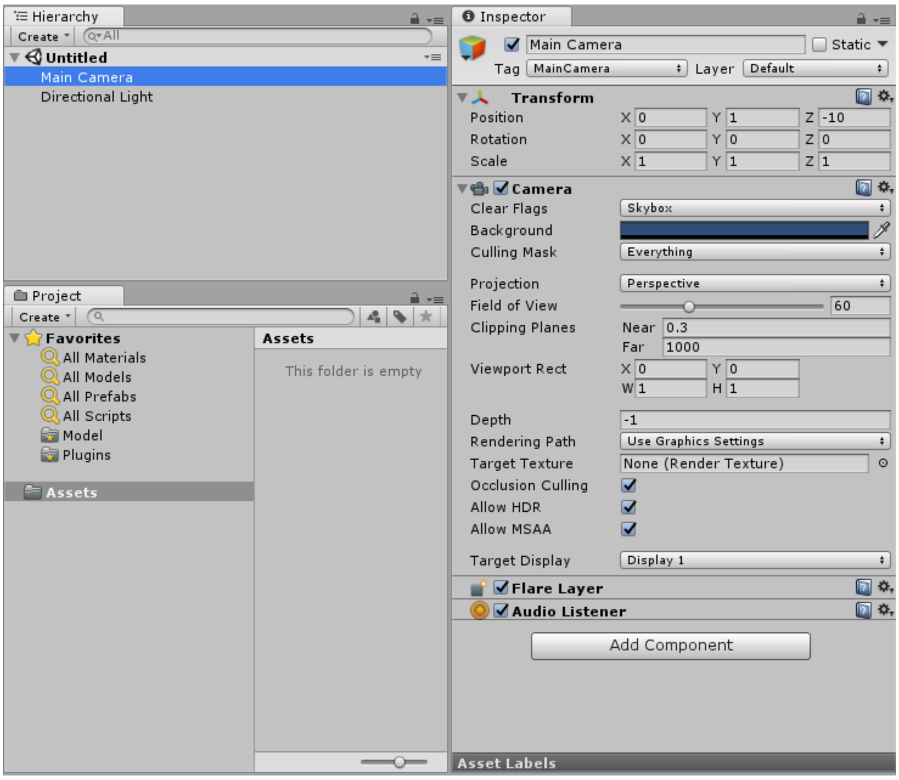


Figure 70: Main camera proprieties

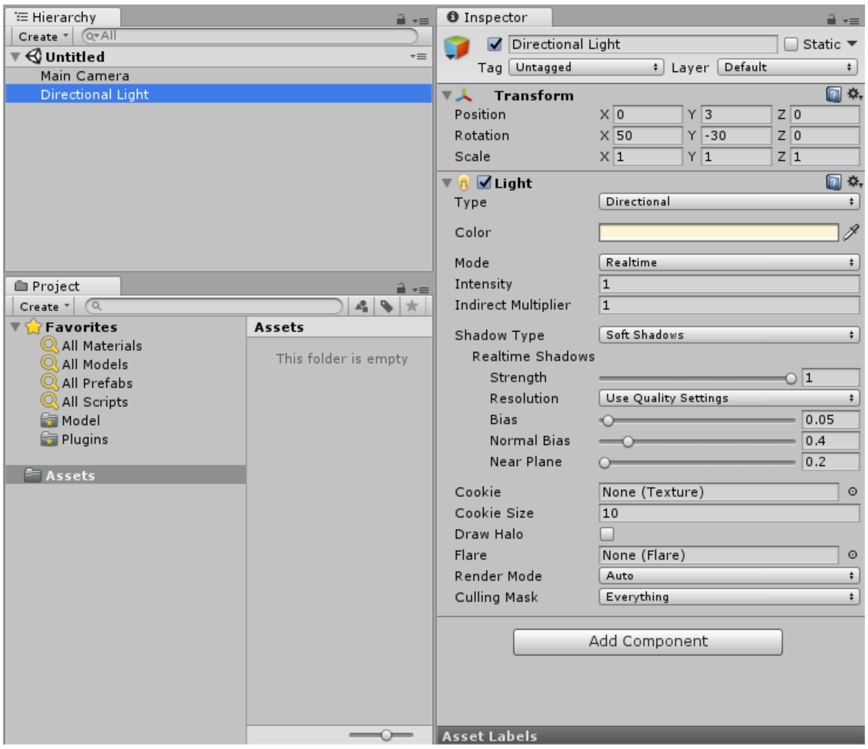


Figure 71: Directional light proprieties

5.3 Version Alpha of Interchange Designer

The alpha version of the interchange designer application was developes based on a 2D representation of the environment. The first step for this version was the use of the existing blueprint of the terminal, map, or a satellite/aerial imagery to be used as a guideline for designing the infrastructure. This image was placed on the layer 0 of the algorithm and had no impact on the calculation. The layer 1 (Figure 72) creates a matrix to store the data related to the infrastructure. The size of the unity was adjustable by the user.

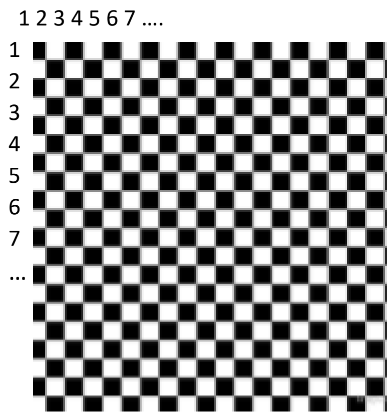


Figure 72: Matrix example for store interchange data

In layer 3, physical constraints are placed to enable the user to place the infrastructure, for example, existing buildings, water (Figure 73) (the terminology occupied was used to represent blocked zone).

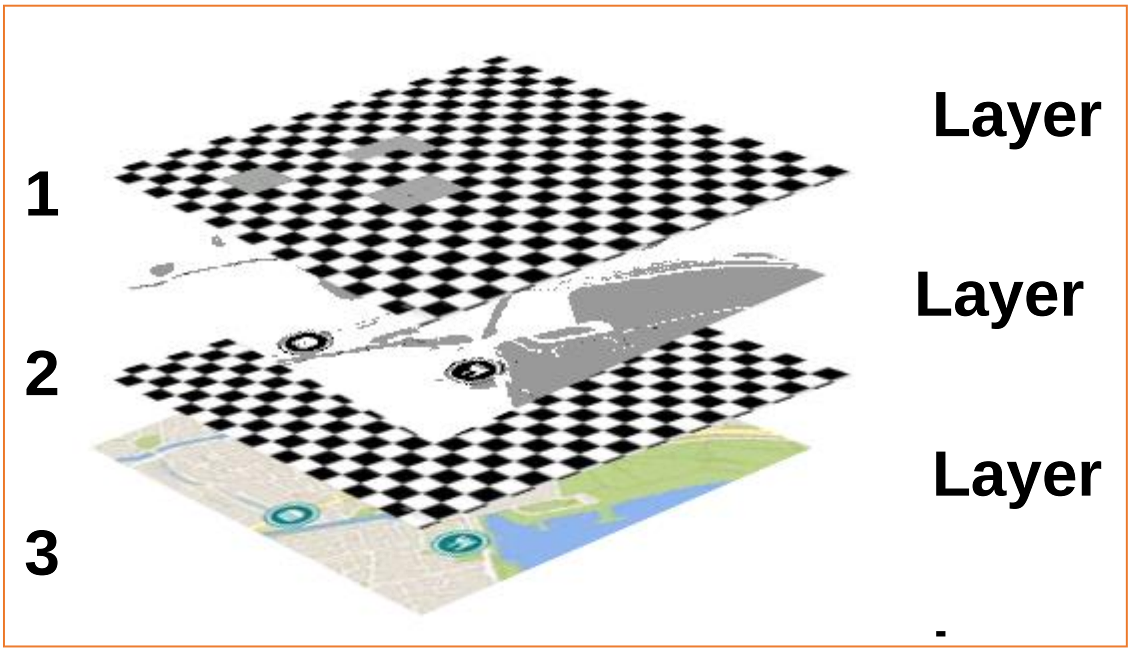


Figure 73: Multi-layer matrix for storing multiple data

After creating the blocked zone (occupied blocks), the user was ready to create a floor (zone of instantiate buildings) or create lines (2 points connection with adjacent blocks) and switch (3 points connection with adjacent squares).

By clicking on the switch button, a menu will open for the user with graphical representation of different switch positions *(inside the red rectangle in* Figure 74*).*

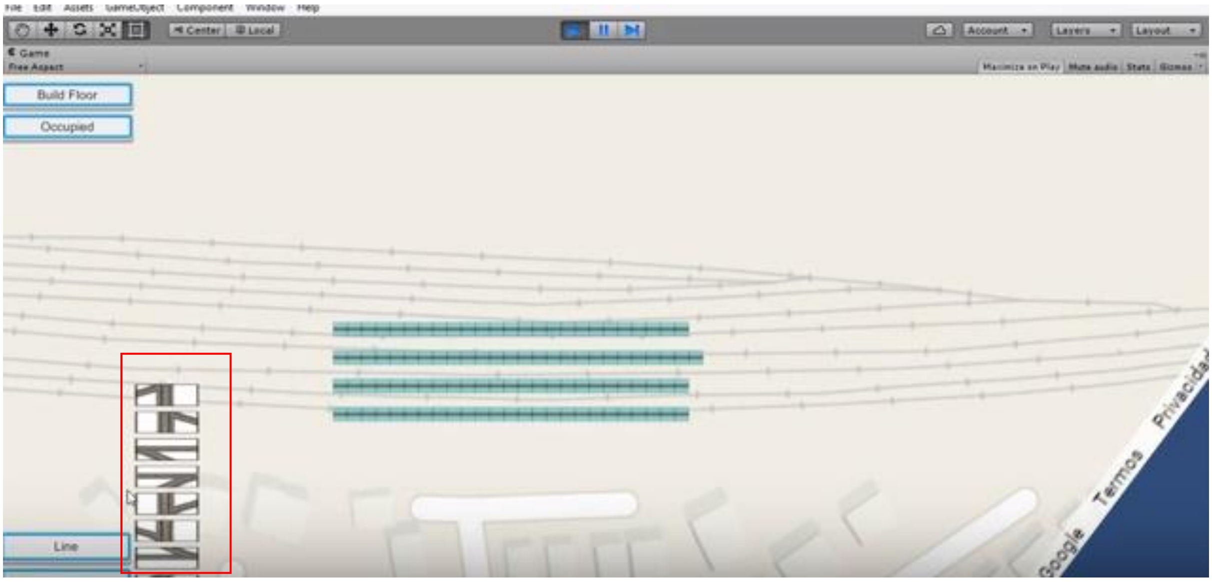


Figure 74: Interchange designer dragging and dropping elements (switch deployment)

All the data relating to the buildings, lines, and switches are stored in a string matrix. The letters on the blocks represent the different infrastructure components. The code was developed in a way to enable 3D printing of the infrastructure. Each letter corresponds to a pre-developed 3D model.

5.4 Version Beta of Interchange Designer

For the beta version, a new approach was adopted to develop the application, and a full 3D environment was developed to enable visualising the designs and changes in real time. The beta version allows better representing the topography of the terrain and the physical constraints of the environment. The representation achievable with the proposed 3D software can use complex 3D model for more realistic representation of the real environment and similar to those achievable by commercial systems such as Autocad or BIM,.

For the new approach, a scenario development strategy was adopted. With this method, a scenario creation tool was developed to create "playable" scenarios. The main advantage of this method is that it enables customizable scenarios depending on the needs of the stakeholders involved, topography and physical elements.

5.4.1 Representation of Software Package Structure

Modern game development systems are predominantly organised in system hierarchies. Hierarchy refers to the framework structure of the file system. The hierarchy can be represented as a tree, with the root of the file hierarchy corresponding to the root of the tree or as workflow with the interconnection between the elements and structures.

In Unity and other game engines, the scripts (piece of code with rules and commands) are attached to game components, and by the global variables, the different scripts can interact with each other, controlling the behaviours of the multiple elements.

The different scripts are attached to game objects, prefabs, and buttons. The scripts also provide outputs for the texts elements. Some game objects influence and are influenced by multiple game objects and scripts according with their roles and objectives. Figure 75 illustrates how some game objects are connected and where it collects inputs. A comprehensive overview of the scripts is presented next to describe the role of all the scripts, main characteristics, and their interdependence.

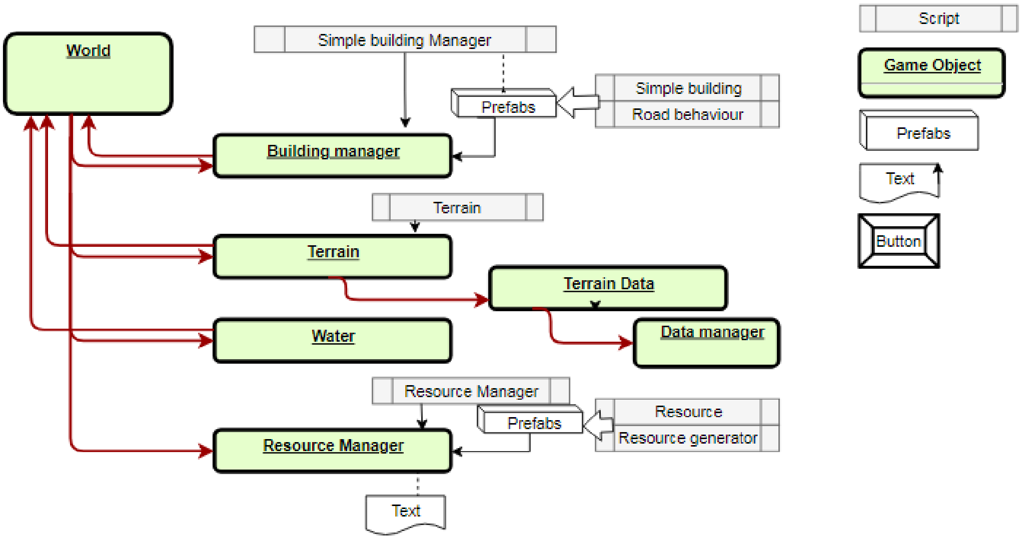


Figure 75: Interrelation between scripts, game objects, prefabs, and interaction

The game object "World" is instantiate when the software starts and creates 4 other game objects. The "Building manager" game object receives a number of commands from the Simple building manager scripts, including a list of possible buildings able to be deployed in the scenario. The same script is also attached to Prefabs (for example buildings to be deployed and their behavior). All the data collected return to the "World" game object in a predefined speed (every frame, for example).

The terrain game object receives an object the size of the world from the "World" game and receives the commands to be executed every frame or according with the user interaction from the Terrain script. The data from the "Terrain" are stored in the "Terrain data" and provide the inputs for the Data manager.

The framework used for the Interchange designer is organized in 4 main families of scripts designed to be applied to the 4 categories of game objects (user interface, world, buildings/resources, and data) as illustrated by Figure 76. Each component may contain a number of individual scripts (C#) with local and global variables.

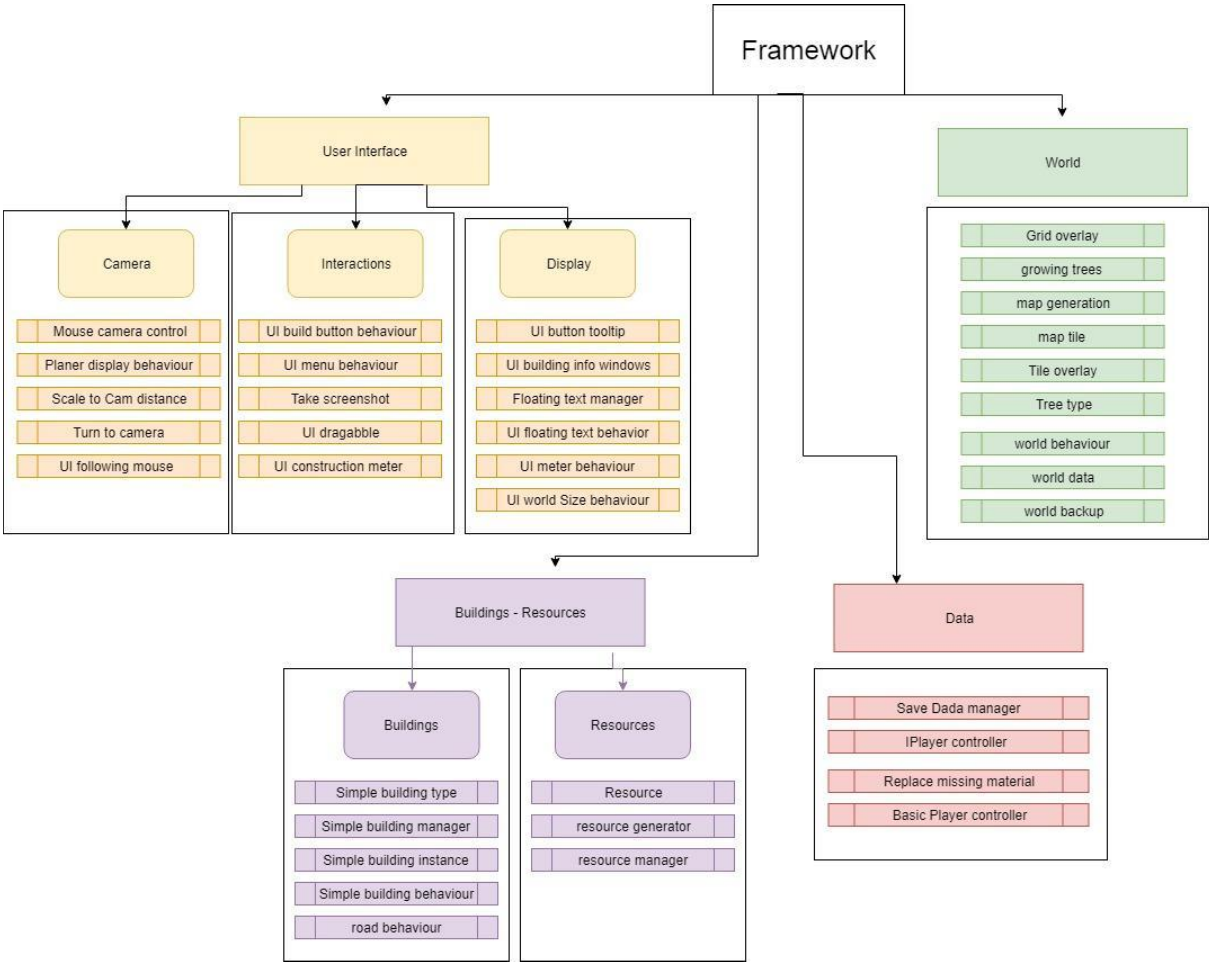


Figure 76: Version beta interchange designer framework: Main scripts

<u>Navigation and graphical user interface</u>

In this research work, attention was dedicated to developing a user-friendly navigation system to provide a maximum intuitive level for the user and, at the same time, require minimum key input by the user.

Traditionally, navigation describes the movement in the screen space and interacting with buttons, folders, and elements in a file hierarchy. Sometimes, the user experience has a direct target, and each step of the navigation is intuitive, involving only scanning the view for an objective and selecting it. Other times, the contents of each interaction require tips and advice to assist users in reaching a target. The graphical user interface is used in the scenario designer, and the

interchange designer tool is used as input (Figure 77):

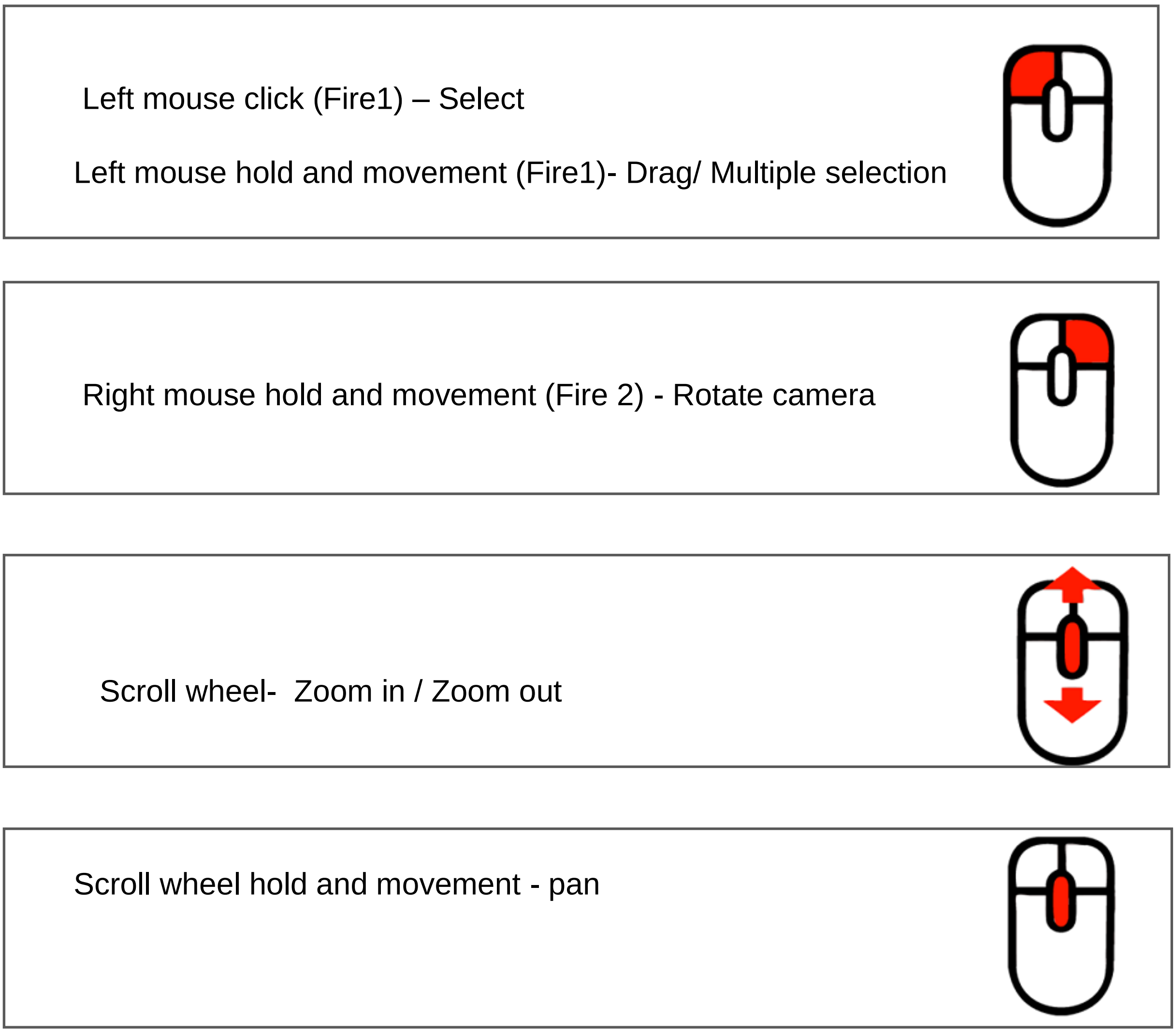


Figure 77: User interface: Navigation

Additional features for a user interface include a text field, navigation buttons, and a preview of the selected item. In order to facilitate a better understanding of the elements, a brief description of the scripts is provided:

Camera Scripts are normally attached to a camera or player. The camera scripts used in the software are:

- **Mouse camera control**

Description: This script read inputs provided by mouse buttons/keyboard and translate in the same order used by Unity (Left = 0, Right = 1, Middle = 2, None = 3, A = mouse movement to the left, S = mouse down, D = mouse right, W = mouse up). It handles mouse movements and scroll parameters.

Methods: Input.GetKey, Input.GetAxis, Mathf.Clamp, transform.rotation.eulerAngles

Parameters: Force Camera

Returns: Camera movement

- **Player display behaviour**

Description: This script (shown in Figure 78) is responsible for displaying terrain transform buttons (and destroy options) in the screen, displaying temporary game objects (before instantiation), controlling indicative cursor (Arrow).

Methods: SetActive bools for change TerraFormType variable

Parameters: BasicPlayerController. Game objects (arrow up, arrow down, imgBomb, tempBuildObjects

Returns: TerraFormType

```
(currentTerraform) {
e BasicPlayerController.TerraFormType.BULLDOZE:
arrowDown.SetActive(true);
imgBomb.SetActive(true);
break;
e BasicPlayerController.TerraFormType.BULLDOZE_AREA:
arrowDown.SetActive(true);
imgBomb.SetActive(true);
break;
e BasicPlayerController.TerraFormType.RAISE_TERRAIN:
arrowUp.SetActive(true);
break;
e BasicPlayerController.TerraFormType.LOWER_TERRAIN:
arrowDown.SetActive(true);
break;
e BasicPlayerController.TerraFormType.LEVEL_TERRAIN:
arrowDown.SetActive(true);
imgLevel.SetActive(true);
break;
e BasicPlayerController.TerraFormType.BUILD:
arrowDown.SetActive(true);
imgTurnArrows.SetActive(true);
```

Figure 78: : Player display behaviour: terraformType

- **Scale to camera distance**

Description: The objective of this script is to create distance scale with max and min distances to enable zoom function.

Methods: Vector3.Distance, transform.position, Mathf.Lerp

Parameters: Camera

Returns: transform scale

- **Turn to camera**

Description: This script aims to change the camera orientation horizontal / vertical.

Methods: transform.up, transform.forward, switch

Parameters: Camera.main

Returns: TerraFormType

- **UI follow mouse screen space**

Description: Script responsible for display UI in screen following the same mouse position.

Methods: transform, input.mousePosition

Parameters: mouse position

Returns: Game object position

The second category of scripts with focus on user interface and the scripts related to the interaction process. Those scripts are related to the transformation of the inputs in the game objects by the user interaction:

- **UI build button behaviour**

Description: This script is responsible for handling clicks in the buttons (e.g., buildings). As it can be seen by the example of the code (in Figure 79), the script applies different methods in different game objects.

Methods: this, GetComponent, GetComponentInChildren, AddListener

Parameters: game.Object, buildingType.name

Returns: SetBuildingType

```
// Update is called once per frame
void Update () {

}

public void Setup(SimpleBuildingType buildingType, IPlayerController
    this.buildingType = buildingType;
    this.player = player;

    gameObject.name = buildingType.name;
    GetComponentInChildren<Text>().text = buildingType.name;

    UIButtonTooltip tooltip = GetComponent<UIButtonTooltip>();
    tooltip.tooltipObject = buildingType;
    tooltip.txtTooltip = txtTooltip;

    GetComponent<Button>().onClick.AddListener(HandleClick);
}

public void HandleClick(){
    player.SetBuildingType(buildingType);
}
```

Figure 79: Build button behaviour

- **UI button tooltip**

Description: This script aims to help to display tooltip text information.

Methods: SetActive, ToString, GetComponent

Parameters: GetChild.GetComponent<text>

Returns: text tooltip

- **Take screenshot**

Description: Script developed to enable taking multiple screenshots using F10 key.

Methods: GetKEyDown(KeyCode.F10)

Parameters: if ,Screen Capture, Get.

Returns: ScreenCapture.CaptureScreenshot(filename)

- **UI draggable**

Description: This script is responsible for enabling OnDrag function, getting a list of id elements inside draggable area (mouse enter/mouse exit).

Methods: Input.GetMouseButton, Input.mousePosition, switch (renderMode)

Parameters: mouse position

Returns: elements ids

- **UI construction meters**

Description: Script for reading the time required for complete building construction .

Methods: GetComponentinParent

Parameters: SimpleBuildingBehaviour

Returns: Game object meter

The last category of user interface scripts is the display category aiming to present useful information for the user on screen.

UI button tooltip

Description: This script is responsible for displaying tooltip about the elements in the menus.

Methods: GetComponent, gameObject.SetActive

Parameters: Component

Returns: text (txtTooltip)

UI building info windows

Description: Script designed to display information about the different elements (name, consumption, production).

Methods: building.buildingType.name, building.GetComponent,

Parameters: building type

Returns: text about the building (name, consumption, production).

Floating text manager

Description: Script to display static text about the infrastructure instantiated on screen.

Methods: GetComponent

Parameters: floatingTextPrefab

Returns:Resource text

UI floating text behaviour

Description: The objective of this script is to display and control disappearing text on screen.

Methods: GetComponent, gameObject.SetActive, transform.position, transform.rotation.

Parameters: Vector3 position.

Returns: gameObject text (fading out).

UI meter behaviour

Description: This script performs constant transformation ration in image or creates fill ratio for non-square transformation.

Methods: GetComponent image, imageTransform.sizeDelta.

Parameters: image, originalWidth.

Returns: new Vector2(originalWidth * newRatio.

UI world size behaviour

Description: This script, display and control map size (world size).

Methods: Mathf.Clamp, Mathf.Pow.

Parameters: currentSize , OnIncreaseSize, OnDecreaseSize.

Returns: new word size.

Figure 80 illustrates the user interface elements and the action of the script resulting from the interaction.

Figure 80:Interface elements interaction

Using the button "raise" (1), the topology level created increases; the button "lower" (2), decrease the terrain level; the button "level" (3) allows creation of an area where the level is harmonized. When the mouse button (fire1) is pressed and the mouse moved, a square area is created. When the button releases all the terrain elements in the square, the area receives the same level of the point where the button is pressed.

The button + and – (4) enable the user to decide the scenario total area. With the 3D representation, a vector3 matrix is created storing the data in regard to the X, Y and Z axis. With a 256x256 matrix, for example, 65.536 game elements can be stored in the save file. For scenarios with lower complexity level, a 32x 32 or a 64 x64 is recommended to reduce the CPU usage. While the memory requirements for complex scenes may seem significant, it is important to note that no other demands are placed on memory resources throughout the entire development environment.

The button 5 (restart) creates a procedural scenario topology using the geographic variables. The squares below water level are represented by the blue color (water) and are designed to accept a reduced number of buildings (ports, naval platforms, or piers).

Button save (6) allows to store all topology data to be used in a simulation scenario; the button load (7) opens previously saved data. Clear save (8) deletes data stored, saving memory space and improving performance.

Most of these components are controlled by the scripts in the world section in Figure 81.

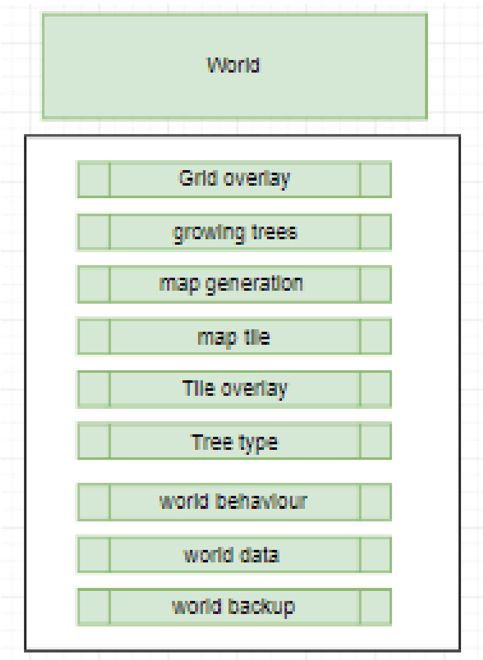


Figure 81: World scripts

Map Tile

Description: Script to create the map tile (slots) category in the world (e.g., flat = 0, leaning =1, ocean = 2, other = 3, flat or leaning = 4).

Methods: this

Parameters: start.x, stop.x, start.y, stop.y

Returns: tiles types

Grid overlay

Description: This script (Figure 82) creates the material and colour for the map slots (squares) and cross (interconnection between squares).

Methods: Color, material, GL, Mathf. An example of the methods can be seen in Figure 83.

Parameters WorldBehaviour world,

Returns: ScreenCapture.CaptureScreenshot(filename)

```
int stopZ = Mathf.RoundToInt( lsStart.z > lsStop.z ? lsStart.z :lsStop.z);

switch (overlayType) {
case OverlayType.SQUARE:
    for (int x = startX; x < stopX; x++) {
        GL.Vertex3( x + wsOffset.x, world.GetHeight(x,startZ) + offsetY + wsOffset.y, startZ + wsOffset.z);
        GL.Vertex3( x+1+ wsOffset.x, world.GetHeight(x+1,startZ) + offsetY+ wsOffset.y, startZ + wsOffset.z);

        GL.Vertex3( x+ wsOffset.x, world.GetHeight(x,stopZ) + offsetY+ wsOffset.y, stopZ + wsOffset.z);
        GL.Vertex3( x+1+ wsOffset.x, world.GetHeight(x+1,stopZ) + offsetY+ wsOffset.y, stopZ + wsOffset.z);
    }

    for (int z = startZ; z < stopZ; z++) {
        GL.Vertex3( startX + wsOffset.x, world.GetHeight(startX,z) + offsetY+ wsOffset.y, z + wsOffset.z);
        GL.Vertex3( startX + wsOffset.x, world.GetHeight(startX,z+1) + offsetY+ wsOffset.y, z+1 + wsOffset.z);

        GL.Vertex3( stopX + wsOffset.x, world.GetHeight(stopX,z) + offsetY+ wsOffset.y, z + wsOffset.z);
        GL.Vertex3( stopX + wsOffset.x, world.GetHeight(stopX,z+1) + offsetY+ wsOffset.y, z+1 + wsOffset.z);

    }
    break;
case OverlayType.CROSS:
    for (int x = startX; x < stopX; x++) {
        GL.Vertex3( x + wsOffset.x, world.GetHeight(x,(start.z + stop.z)/2) + offsetY+ wsOffset.y, (start.z + stop.z)/2 + wsOffset.z);
        GL.Vertex3( x+1 + wsOffset.x, world.GetHeight(x+1,(start.z + stop.z)/2) + offsetY+ wsOffset.y, (start.z + stop.z)/2 + wsOffset.z);

    }

    for (int z = startZ; z < stopZ; z++) {
        GL.Vertex3( (start.x + stop.x)/2  + wsOffset.x, world.GetHeight((start.x + stop.x)/2,z) + offsetY+ wsOffset.y, z + wsOffset.z);
        GL.Vertex3( (start.x + stop.x)/2 + wsOffset.x, world.GetHeight((start.x + stop.x)/2,z+1) + offsetY+ wsOffset.y, z+1 + wsOffset.z);

    }
    break;
```

Figure 82: Grid overlay script

Tile overlay

Description: The objective of this script is to enable set colour in real time for the slots (tiles). Draw tiles that are OK in green and non-OK in red.

Methods: GL.Color

Parameters: tiles[x,y],

Returns: tiles color

Growing trees

Description: This script creates and enables growing trees.

Methods: Mathf.Min

Parameters: tree instances

Returns: tree sizes (OnFinishedGrowing)

Tree types

Description: This script defines the data of a certain tree type and calculates how optimal a height can be considered for a particular tree type.

Methods: Mathf.Max

Parameters: Create menu for tree

Returns: Tree types

With the menu to create a new tree type, we need to create a new scriptable object to represent the data of the new tree type (prefab of the tree). To set up the new “Tree Type” prefab, we need to go in the Unity Terrain Object tab (Components > Miscellaneous > Terrain) as shown in Figure 83.

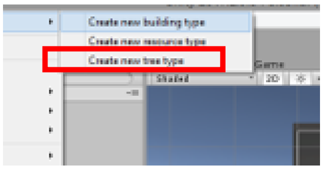


Figure 83: Creating trees

Now, by clicking on [Edit trees] in the Terrain object and selecting [Add tree], we will be able to import different 3D models of trees from the library to create the new tree prefabs. The Terrain component handles tree prefabs as “Tree prototype”. It indicates a number for each specific tree type; for example, oak above has index 0 , the pine has index 1, the conifer number 2, and the last tree (nature pack_0) the number 3. In a procedural generation, a random algorithm is used to select these numbers and place the tree in the terrain. For placing trees manually, a mass placement tool for tree components was created to enable quickly customizing the scenario (Figure 84).

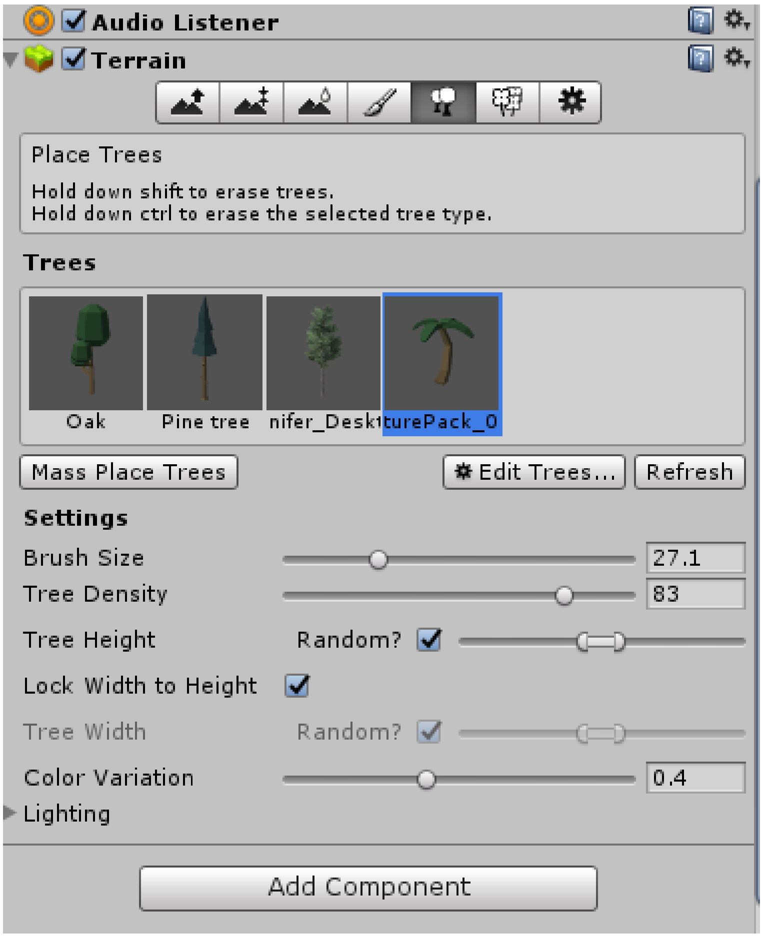


Figure 84: Tree design options

The last step is to tell the world manager that it should use this tree for world generation. After adding a *Tree Type* scriptable object to this list, and our tree can now be used at procedural world generation. The same method can be adapted to place other objects (houses, buildings, streets) according to user need.

Map generation

Description: Create a menu for using random distributions (linear, Gaussian, square_root, two_rands, three_rands) for elements to create a procedural map.
Methods: Random.Range, Mathf

Parameters: create menu for hillyness, treeyness , wateryness (as it can be seen in Figure 85)

Returns: world procedural elements menu

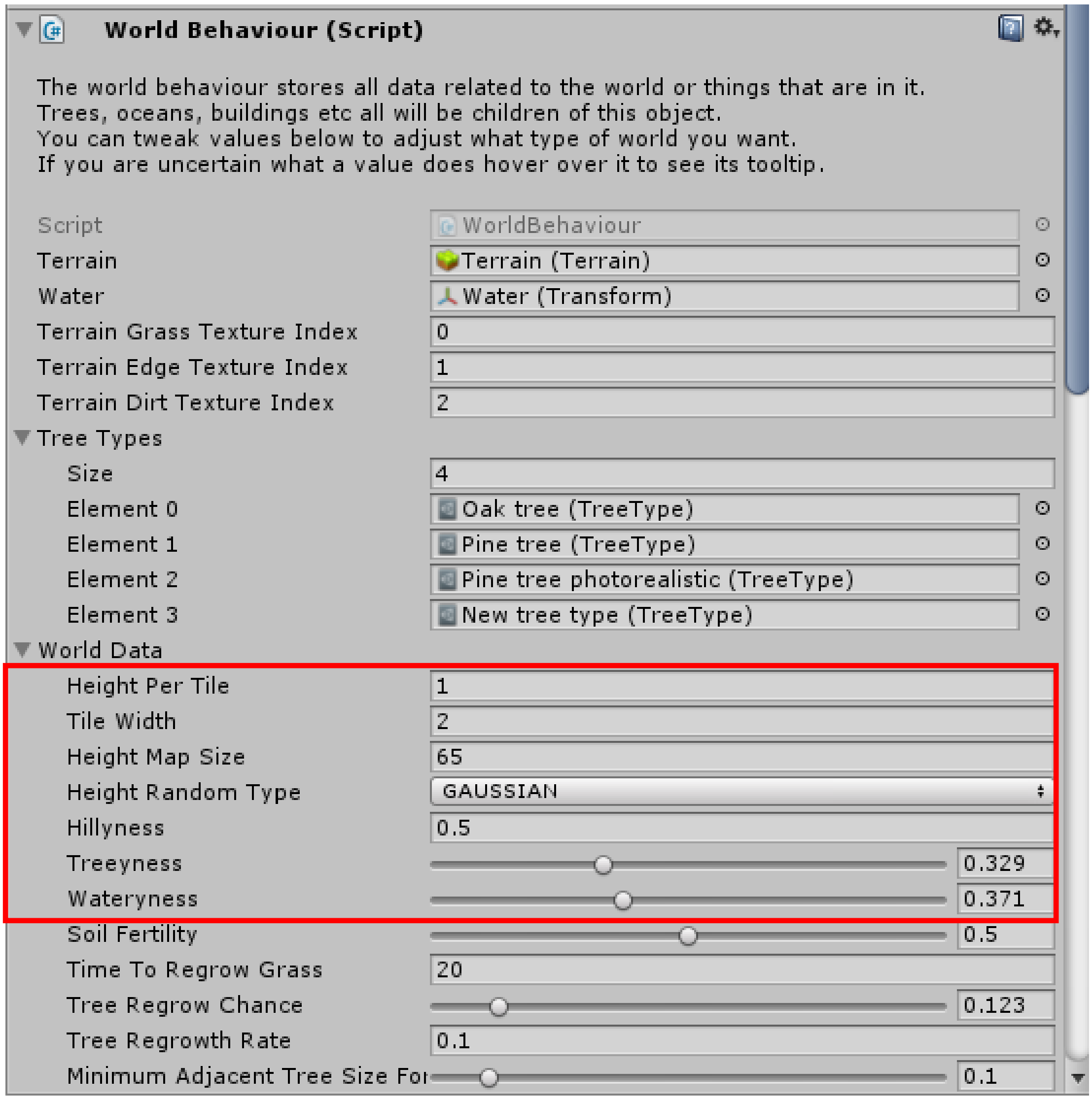


Figure 85: Map generation options

World behaviour

Description: This is the most complex script and process in all world gen and terraforming. Data are transformed for easy serializing process.

Methods: FormerlySerializedAs, Dictionary, List, Queue, IEnumerator, foreach, for, Random, SaveDataManagement, Mathf

Parameters: TileMapSize, MapTile

Returns: Tile.position (x,y) , Tile.height (z) , Tile.contains, Tile.position, Tile.fertility

World data

Description: Store world data saved between sessions and enable loading. As the xml serialization did not support multidimensional (vector 3), an alternative method was used, potentially causing some garbage.

Methods: FormerlySerializedAs , Xml.Serialization

Parameters: MapGenerator and World behaviour

Returns: serialized xml

World backup

Description: Stores all data related to the world or things in it. Trees, oceans, buildings etc. all will be children of this object. Enable tweak values to adjust what type of world is needed.

Methods: override

Parameters WorldBehaviour

Returns: original WorldBehaviour parameters

With the world created, a fundamental concept for creating scenarios in the interchange designer tool is the resource function. Resource functions are used to represent the key performance indicators of the interchange. The type of resources available and the quantity of each user can be displayed in real time based on the cost of the elements placed on the terrain. All resources are controlled by the resource manager script and work as prefabs (Figure 86).

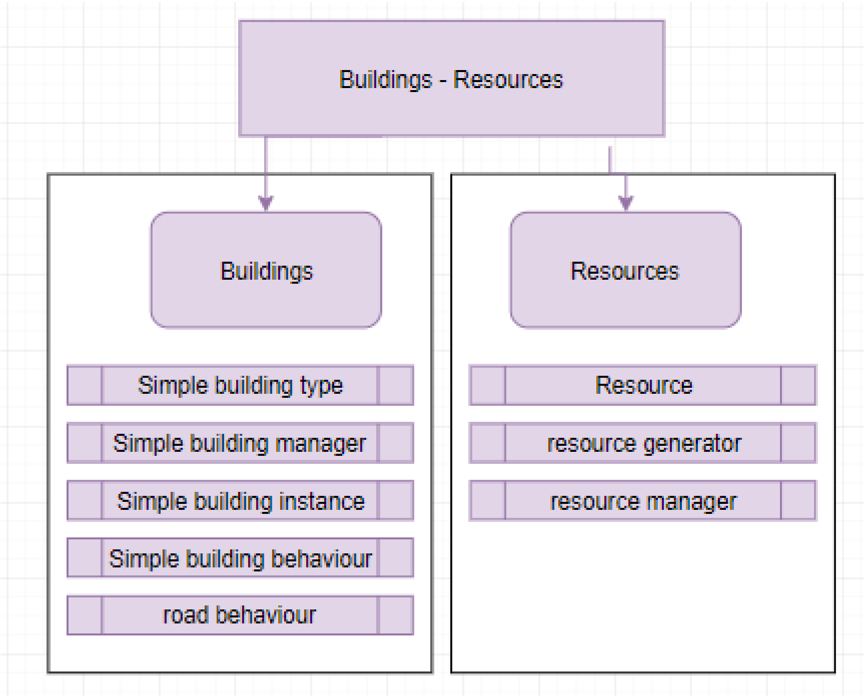


Figure 86: Building and Resources scripts

Figure 87 shows the 3 scripts related to the resources that can be seen in the asset section.

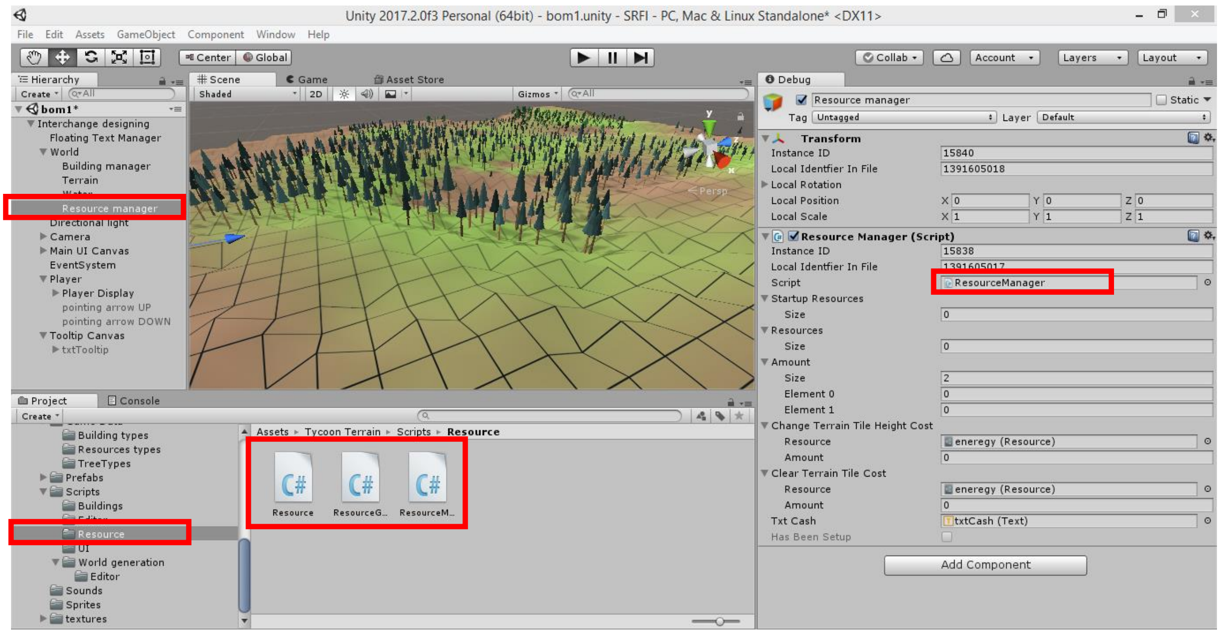


Figure 87: Resources Scripts folder and configuration

.

Resource

Description: This script can be applied to the resource that can be used to construct infrastructure/buildings.

Methods: override string, Serializable

Parameters: resource (asset)

Returns: resource menu (name, amount)

Resource generator

Description: This script needs to be applied to resources that are generated by the infrastructure in the terrain; for example, transshipment equipment can be configurated to generate container movement, and a commercial building can be employed to generate “commercial trade” or “employment” when instantiating or over the time. The KPIs and values adopted in each scenario depend on the existing data and the desired scenario.

Methods: yield while, return , Random.Range

Parameters: ResourceManager

Returns: resource

Resource manager

Description: Script applied to the resource that can be used to construct infrastructure/buildings.

Methods: List, foreach, IEnumerable, return CalculateCost(cost)

Parameters: ResourceInstance resources, Resource cost; CanAfford(item)

Returns: resource amount for display, error message

By applying the resource script to the game object in the hierarchy section, we can visualize the proprieties in the inspector section. In order to create a new resource to be controlled by the resource manager, we need to create a new resource following the same path we used to create new three prefabs (Figure 88).

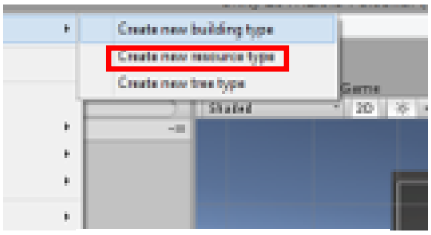


Figure 88: Resource creation

By clicking on the “creating new resource type” option, the system opens a new tab (illustrate in Figure 89) where the user can create a new resource. The C# script “resource” is automatically attached to the prefab, and the user can name the resource and define a prefix or a suffix for the prefab. The prefix/suffix will be displayed on the screen with the respective values.

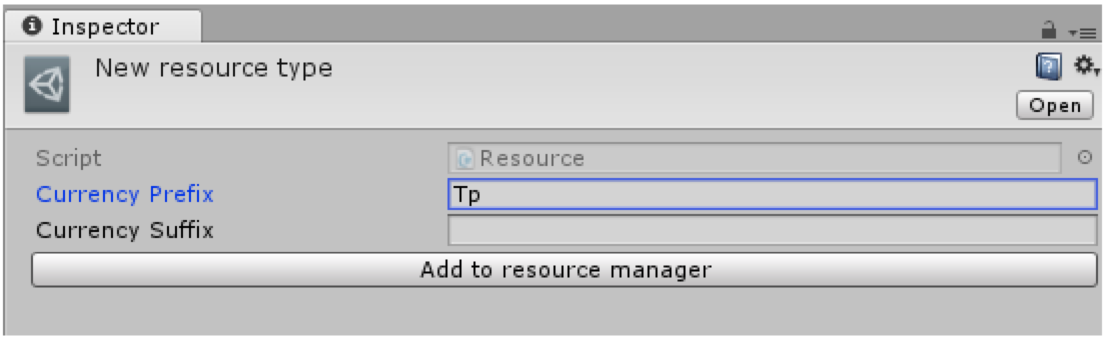


Figure 89 :New resource configuration

The values/costs assigned for each building are inserted in the building configuration. Before adding the new infrastructure to the building manager, we need to create a prefab. We can do this by selecting the option to create>prefab. To assign a 3D model for this prefab, we can drag and drop the 3d file into the new prefab created (Figure 90). This 3d file will be represented by this new prefab in an optimized way for the unity. All instances of the model could be counted by the unity as a single unity, reducing the memory costs. The next step is to attach the script *SimpleBuildingBehaviour into the prefab.*

Figure 90: Importing 3d models- assets creation

This script enables us to set up additional assets, such as “Planned Building”, which is a representation of the building before instantiation in the terrain, “Under Construction Building” representing an incomplete version the infrastructure, “Finished Building” representing a final version of the infrastructure, and “Razed Building” representing a destroyed version of the infrastructure. For each version of the building, a different version of the 3d model can be imported with different animated scenes, textures, or colours.

The five scripts related to the building category allow the system to understand the characteristics of the building and how they impact the other scripts.

Simple building type

Description: Script to create new Asset Menu to be edited in the inspector window

Methods: Serializable, List

Parameters: MapTile, MapTileType, GameObject prefab, Time to build

Returns: user inputs

Simple building manager

Description: This script allows adding and removing buildings in the world. Look to determine whether the building position is allowed at the specified x, y and direction and adjust based on the user preference; for example, if a building is rotated (-90 or 90 degrees), then switch width and length. A dictionary function is transformed into an array to enable saving.

Methods: Dictionary, List, foreach, GameObject.Destroy,

Parameters: SimpleBuildingType, WorldBehaviour, SaveDataManagement, MapTile, Collider, SimpleBuildingInstance

Returns: MapTile, List,

Simple building instance

Description: Script for building instance status data that is saved between sessions (e.g.: planned, building, finished, razed)

Methods: this, Serializable

Parameters: key, position (x,y)

Returns: building Type Index

Simple building behaviour

Description: This script enables different 3d models to change its looks in different states.

Methods: switch, while, yield

Parameters: SimpleBuildingType, SimpleBuildingInstance

Returns: Building Changing State

Road behaviour

Description: Enables adjusting road and rail tiles to "lean with terrain". If the tile does lean, then the graphical representation is stretched; it goes up a hill reaching all the way.

Methods: transform (vector3 scale)

Parameters: Space.World (scale.z)

Returns: transform localScale

With the prefab created and the building scripts, we can now add the new building to the building manager by clicking on the “create new building type” option Figure 91).

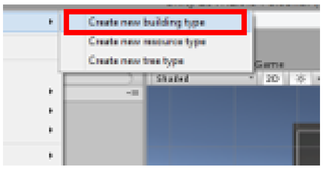


Figure 91: Creating building

By selecting this option, a new building asset will be created in the folder opened, and a new tab will be available in the inspector as shown in Figure 93.

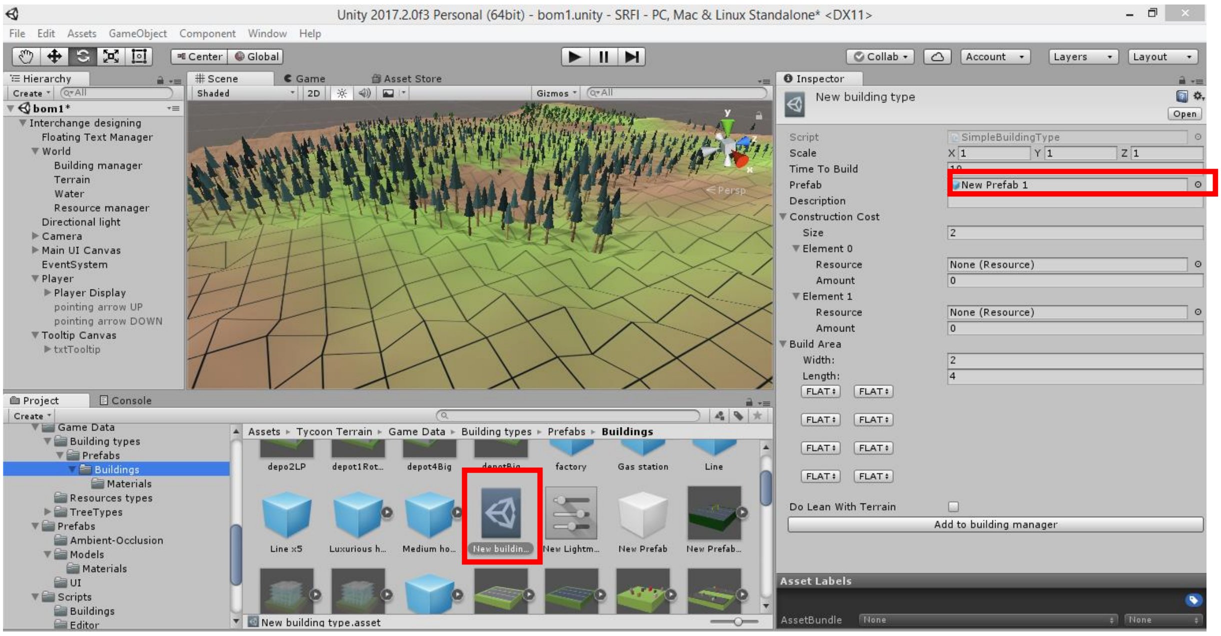


Figure 92: Creating a building prefab

The desired prefab need to be dragged into the prefab options and define how many and the type of resources that will be assigned for this element. We also can define how many slots this building will occupy in the terrain and the terrain type (flat or water). Some buildings can/must be placed in the inclined terrain (lean). By clicking the option “do lean with the terrain”, the element can be placed anywhere. By using the script, we do not have to set resource values for children of the prefab in the different states. The script will activate the state according to the time to build (in seconds). The calculation time depends on the used computer specs. All the simulations in this work were executed in a PC with an intel processor (core i5) 8MB memory ram.

The “new building” asset in the example takes the “new prefab 1” as 3d representation, takes 10 seconds to build, uses two different resources, and occupies eight slots (2x4).

The last group of scripts is those related to the data (Figure 93):

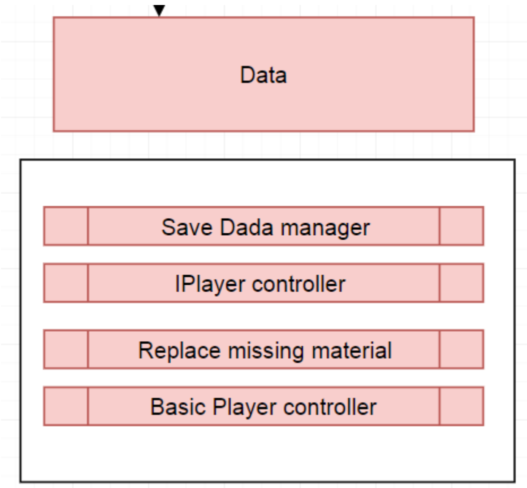


Figure 93: Data scripts

Save Data manager

Description: Script designed to use and enable PlayerPrefs component to create save control system with serialize/ deserialize xml.

Methods: Serialization

Parameters: PlayerPrefs

Returns: serializable/ deserializable xml string

IPlayer controller

Description: This script gets the available building types. Can be used to build prerequisite categories for buildings (buildings that require previous buildings or resources).

Methods: List, get

Parameters: SimpleBuildingType

Returns: AvailableBuildingTypes

Replace missing material

Description: The objective of this script is to scan missing material error, replacing for standard colour.

Methods: foreach, getComponent

Parameters: renderer

Returns: material

Basic Player controler

Description: This script provides the control system for the player. It creates a menu passing all the scripts to be attached to the player component.

Methods: GetComponnet, switch, Mathf

Parameters: WorldBehaviour, TileOverlay, impleBuildingManager, MapTile, TerraFormType, FloatingTextManager, SaveDataManagement, SimpleBuildingType, TerraFormType, PlayerDisplayBehaviour

Returns: Player controller

In order to provide an understanding of the framework, a conceptual map for the scenario designing tool with the main game objects and scripts is presented in Figure 94.

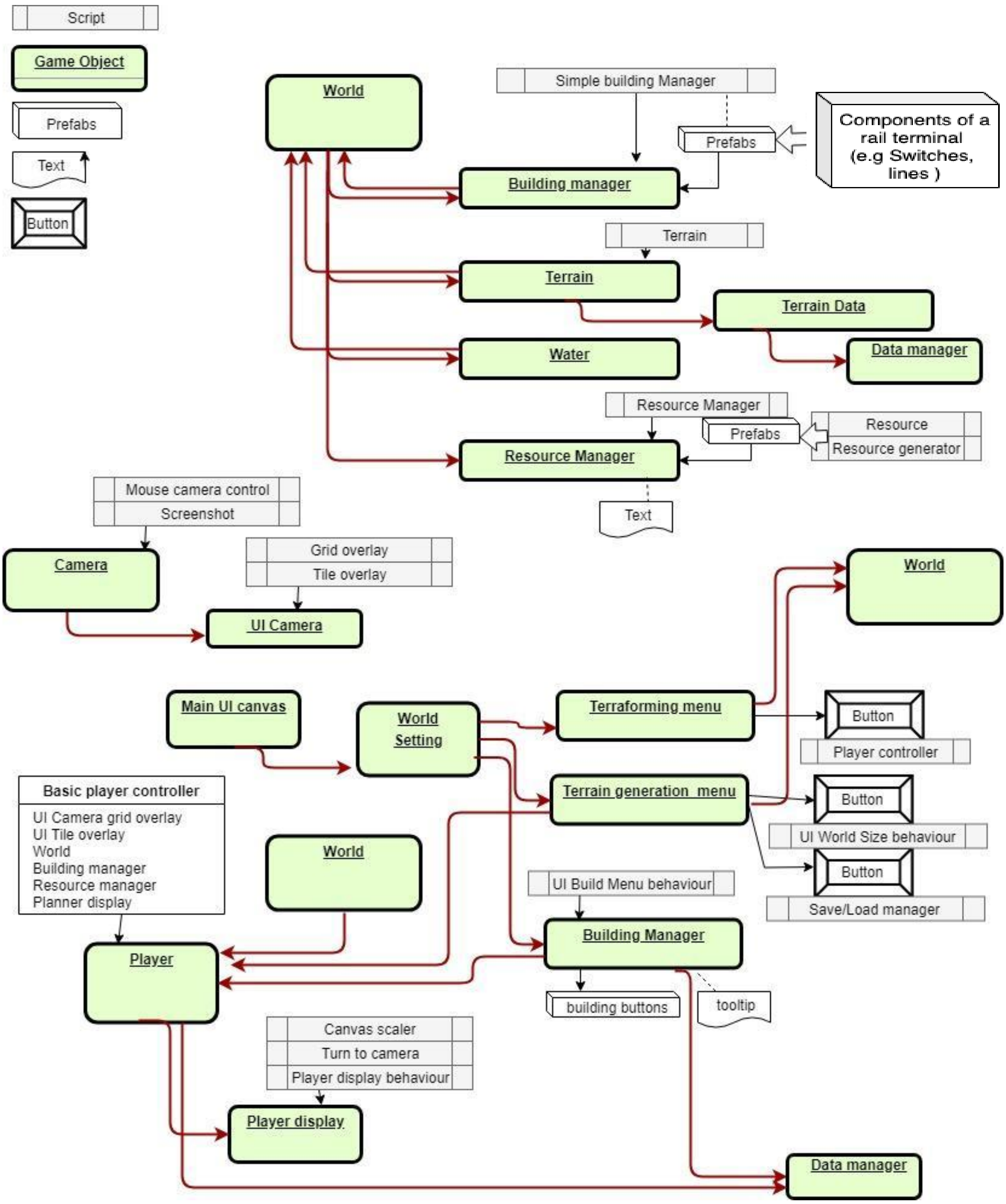


Figure 94: : Interrelation between scripts, game objects, prefabs, and interaction

5.4.2 Creating a Scenario

With all the scripts attached to the game objects and the topology of the terrain developed, as well the resources used and the building options, we are finally ready to create the scenarios. Each finished scenario can be saved in the unity as a game level (Scene), and in the scenario selector menu, the user can select the scenario to simulate. In the initial menu of the software application, the user will see a description of the scenarios (game levels) and, by clicking on the start button (Figure 95), will be able to design the interchange selecting the different infrastructure elements in the buttons menu. The information related to the costs and benefits of the buildings will be displayed in real time for the user according to the instantiated buildings. The terrain deformation options will not be available for the user in order to avoid reusing the scenario for other simulations.

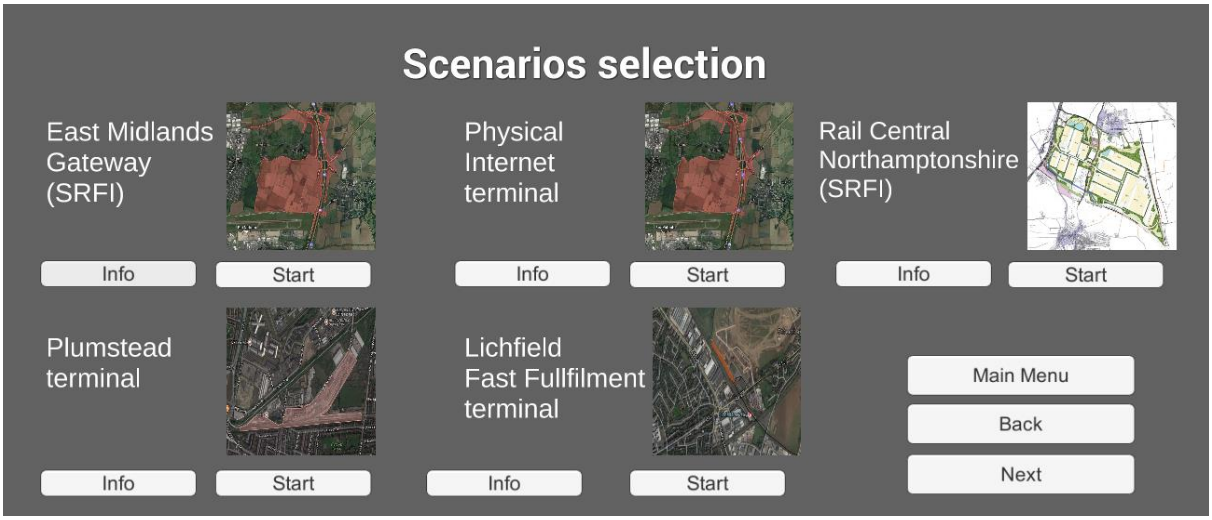


Figure 95: Scenario selection menu

5.7.4 Operating a new scenario

The user-friendly experience was the focus of the scenario development. As it can be seen in Figure 96, when the infrastructure button is clicked, a provisory instance of the building is presented, and when the elements are placed in the terrain, the respective costs are added in real time in the KPIs manager system, helping to understand the impact of each infrastructure. This section presented the ways to configure scenario projects for the interchange.

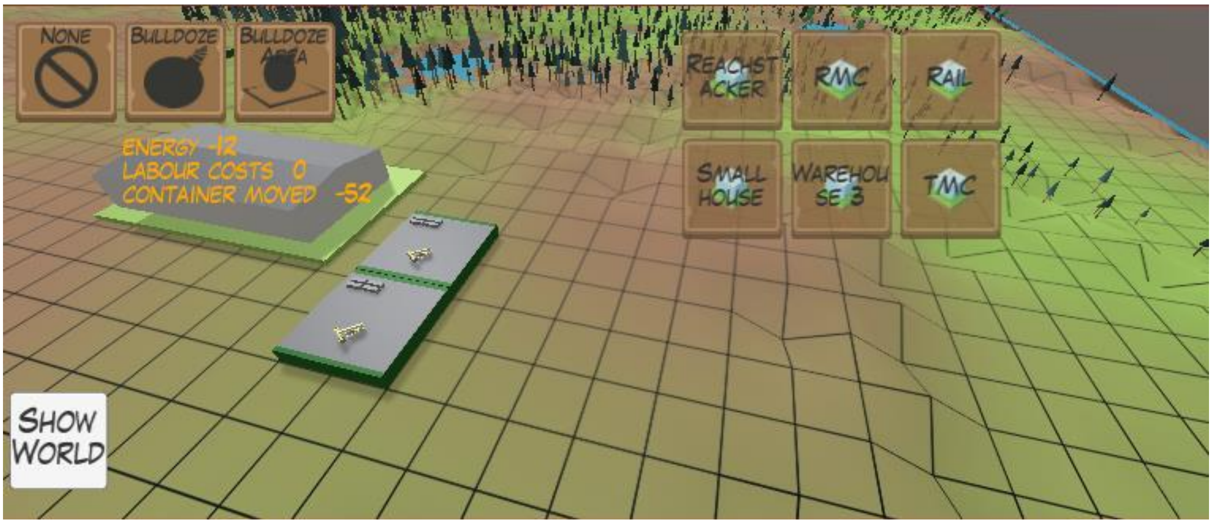


Figure 96: Operating scenario, selecting, and instantiating buildings

5.4.3 Interchange Designer Tool Online Application

Many decision-making processes in infrastructure involve several distinct groups of people working collaboratively; therefore, an online application of the software applications based on shared information and code integration is beneficial for the decision-making process.

In order to create an online design tool, we used WebGL launcher options based on HTTML5 (Figure 97).

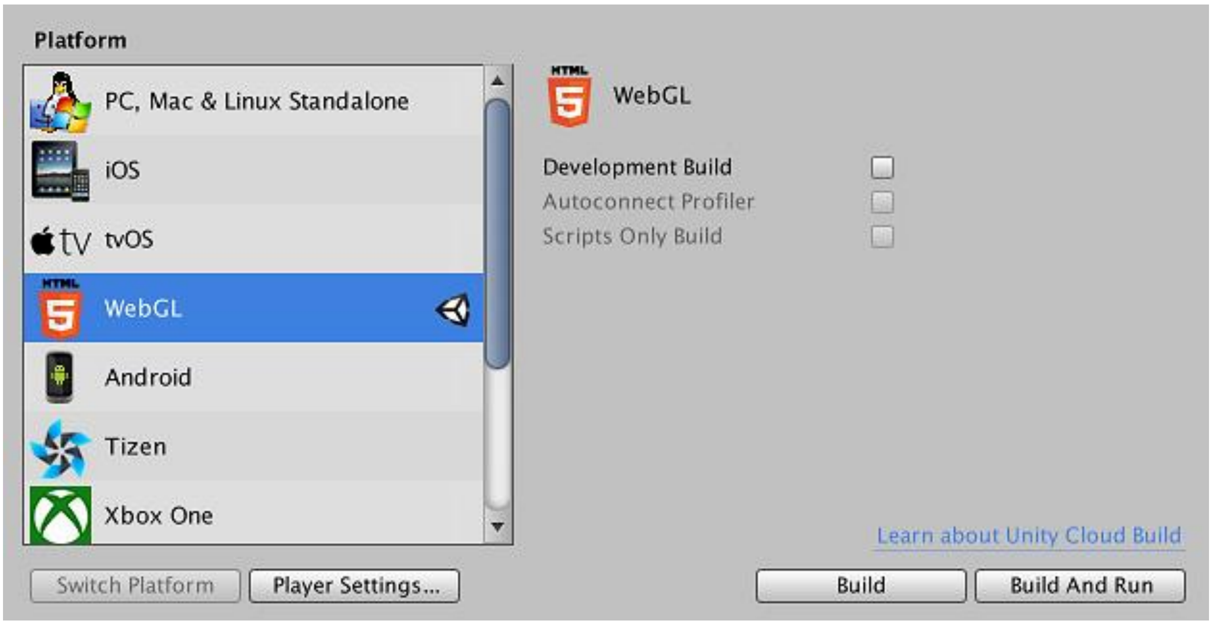


Figure 97: Launching application- WebGL

With the WebGL option, Unity automatically created a folder containing the following files:

- An index (index.html) for the browsers to load the application content.
- A TemplateData folder containing a Java file (UnityPRogress.js), a style.css, and 8 Unity image files
- A Build folder containing all the generated build and output files. This Build folder contains the following files: SRFI.asm.code.unityweb, SRFI.asm.framework.unityweb, SRFI.asm.memory.unityweb , SRFI.data.unityweb , SRFI.json , UnityLoader.js

Using the webGL protocol, a web version of the interchange designer application was uploaded and is now available at www.srfi.smart2city.com

5.8 Virtual Reality Interchange

Augmented Reality and Virtual Reality are technology aiming to merge virtual 3models and images with the real world to create an immersive experience. In recent years, technical development in the hardware devices, coupled with the acceleration in game engines, helped explore the growing graphics processing power creating immersive and affordable hardware and software.

The use of virtual reality on the interchange designer application aims to show the infrastructure designed in an interactive environment. However, this virtual environment needs to resemble the real world with well-developed graphical representation. The existing 3D models in the designing interchange software, unfortunately, were optimized for the performance lacking a high level of graphical realism.

The integration of the XML file generated by the designing tool with the virtual reality package identifies errors during the recognition process due to the Unity compatibility problems with the different camera systems. Therefore, a VR experience was created for the case study using different 3D models.

Significant changes, not only in the 3D models, were required on the number of entities in the screen and user interface to avoid /reduce motion sickness problem. The application helps to illustrate the potential of VR, showing the possibilities of the game engine to visualize rail freight interchanges.

Although Unity offers VR support for Rift headsets, due to hardware limitation, the system was not test with VR using the Rift devices; however, the same navigation system without VR has been developed and tested in a laptop version, emulating a VR headset.. This process involved the recreation of the scenario, manually placing the new 3D objects generated in the Blender in the VR grid.

5.4.5 Chapter Conclusions

Due to the increasing demand for rail freight and the need for the more rational use of the infrastructure, application of new technology on interchange capacities and handling equipment is expected.

The gap identified the existing tools for designing rail freight operations, so multiple stakeholders can be bridged with the new algorithms and procedures. In this chapter, the main concept of the general software package framework developed was presented in order to exemplify how the multicriteria decision-making process methods (e.g., AHP) can be incorporated in the designing tool.

Procedural generation and evolution process was presented using Genetic Algorithm for the interchange elements. Multi-objective search was used, considering the stakeholder priorities.

Chapter 5 presented Game Engine architecture as tool to develop simulation for rail freight interchange. An implementation in Unity3D is discussed and a detailed overview of the main components is presented in order to explain the interchange designer tool. The functionalities, user interface and relationship between functions of the interchange designer tool are explained. The scenario creation is detailed with an implementation example

Significant advantages have been identified on the use of game engines for simulation tools. The flexibility of the toolsets, high fidelity with real physics, and the complete integration objective C indicate that the use of the game engines has strong potential in the engineering field.

Chapter 6: Interchange Designer: case studies

The objective of this chapter is to discuss the implementation of the interchange designer package in three case studies for a decision-making process involving new interchanges designing and equipment selection. The goal is to illustrate the methodology for combining AHP with GA and its implementation with a graphical representation of the interchanges. A comparative analysis of the outputs is present to assess the impacts of infrastructure enhancements on rail freight railway interchanges'.

6.1 Case Study 1 :East Midlands Gateway

6.1.1 Introduction

In the UK, due to the impact of the infrastructure in the network the development of rail freight interchanges is controlled by the executive agency responsible for evaluating the outcomes of town planning (Planning Inspectorate for England and Wales). All projects with significant impact in the infrastructure their approval following the National Planning Policy Framework therefore must presents the benefits of the interchange considering economic impacts, technical, sustainability, and social (e.g., habitats considerations).

Therefore, the previous projects presented for strategic rail freight interchanges offer a rich opportunity for creating models of the interchanges presented in the proposals and testing the interchanges' scenarios for the application tools, simulating different layouts, considering multiple decision drivers.

This first case study for the implementation of the software packages analyses the East Midlands Gateway. After the publication of the National Policy Guidance for strategic rail freight interchanges (DfT2011), Roxhill Development presented a pre-application (Roxhill 2010) for developing East Midlands Gateway. Located in the Midlands (13 miles south of Nottingham, 20 miles North of Leicester (Figure 98), the Park is connected by the road network (direct access to the M1) and is adjacent to the A50 and A453.

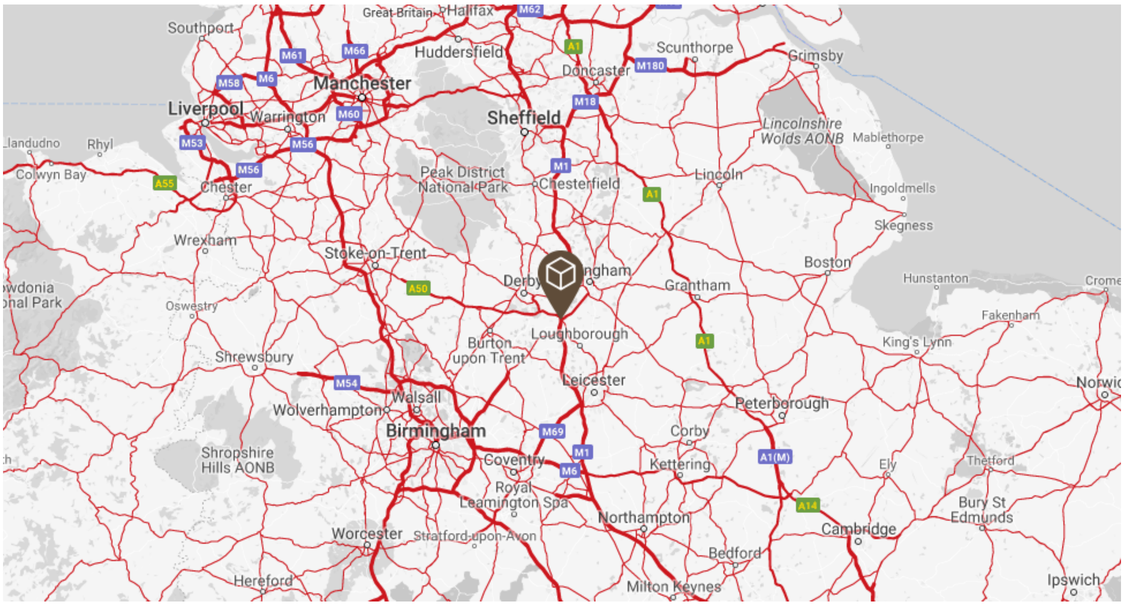


Figure 98: East Midlands Gateway

After the six-step process (pre-application, acceptance, pre-examination, examination, decision, post-decision), the development consent for the Segro Logistics Park East Midlands Gateway (SLPEMG) was given on January 2016.

6.1.2 Main Elements

According to the proposal, the interchange aims to develop the local economy providing:

- 557,414 sq. m of rail served warehousing
- Connection to the rail network (Castle Donnington), with the railway infrastructure to accommodate 12 to 16 trains up to 775m long per day
- Highway connection with arrival and departure roads adjacent to the railway
- Parking area to accommodate the vehicle incoming flow
- Commercial buildings and entertainment areas
- Significant 'Green infrastructure' (75,000 new plants)
- Bus interchange
- Transhipment equipment

Figure 99 illustrates the proposed layout of the interchange and equipment:

Figure 99: East Midlands Gateway proposed layout

For deploying these infrastructure, by clicking on the related buttons, as was discussed Chapter 5, a 3D model of the rail freight interchange assets are required as well the technical characteristics and key performance indicators (KPIs) of the interchange infrastructure.

6.1.3 Rail Freight Interchange Infrastructure Modelling

For the implementation of the Interchange designer tool, a 3D representation of all assets is required. To develop a scenario in this case study, the interchange designing application was configured to accept five rail infrastructure types, four road infrastructure, three transshipments equipment, and four warehouse configurations.

The first step to create the interchange scenario is the development of those representations. The basic rail infrastructure on the interchange designer tool is composed by the rail lines, sleepers and fixation elements. For this case study, a graphical representation of the rail line was created considering a 50-meter straight line. This elements occupy one square on the map (block unit) and can be deployed selecting on the line button. Five grouped squares representing a 250-meter line was created to accelerate the scenario development (button rail 5 in the red square in Figure 100)

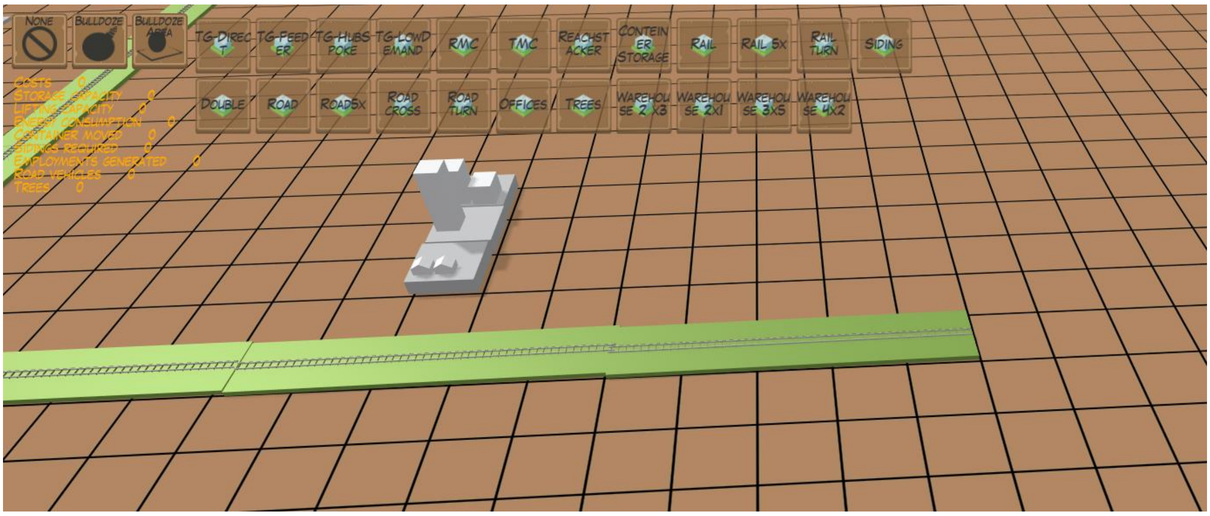


Figure 100: Buttons to deploy Infrastructure types- 250 meter line deployment

Double lines (illustrated on Figure 101) were created with two lines (200 meters extension). The double line block requires/ occupies eight squares (two horizontal x four vertical or four horizontal x two vertical). By clicking in the key A or D the object can be rotate before deployment.

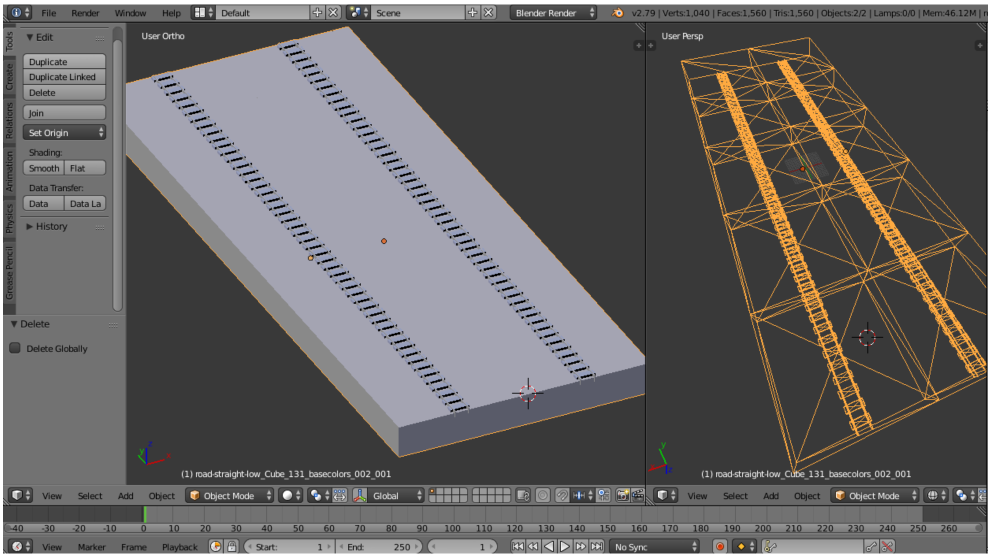


Figure 101: Double line 3D model for designing tool

The rail siding 3D model (illustrated by Figure 102) also requires eight squares on the map and includes approximately 300 meters of rail line to enable joining two lines into one.

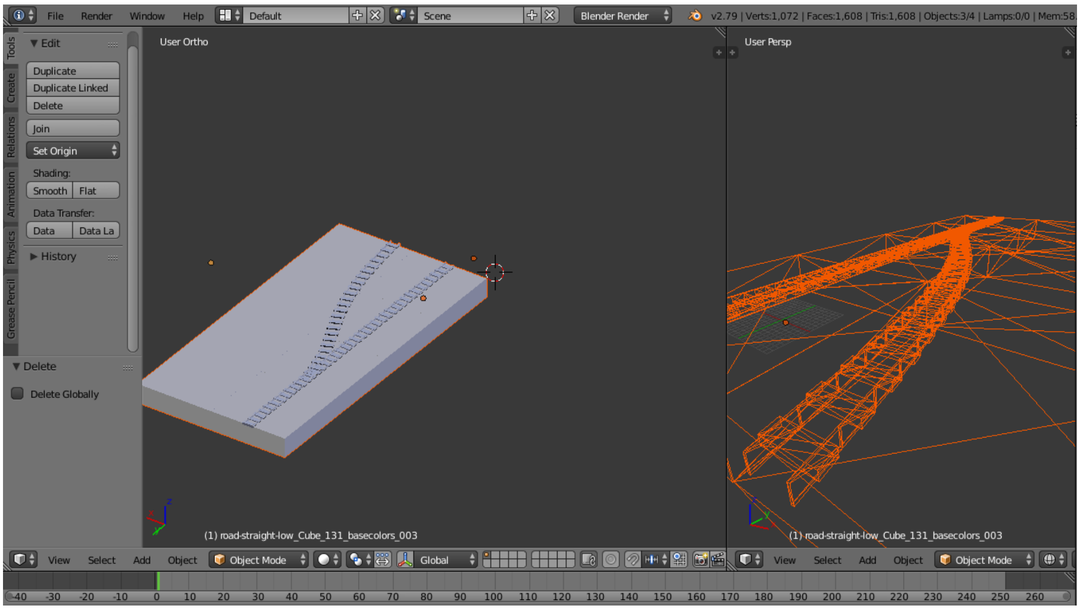


Figure 102: Siding 3d model

To represent rail curves, a simple turn was modelled considering 90 degree turns in 100 meters (two by two block). Additional curve profiles can be created, depending on the need of the users.

To handle the cargo, three main lifting options were created for this case study: Reach stacker (illustrated by Figure 103), Tyre mounted crane, and Rail mounted crane. 3D models of the lifting units were designed to occupy four squares on the map (two by two).

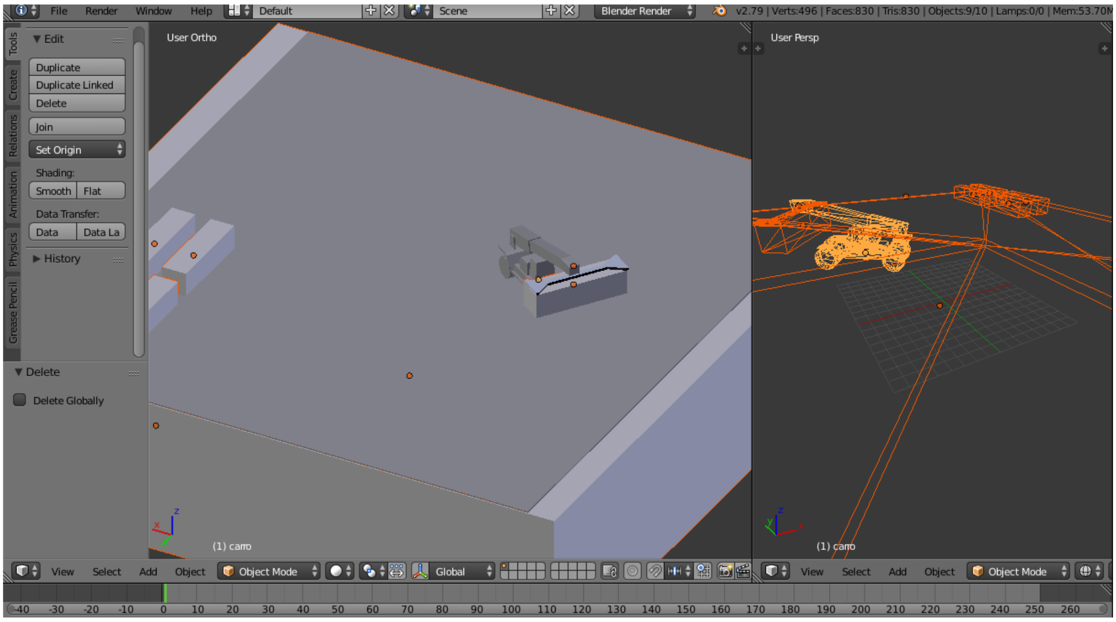


Figure 103: Reach stacker 3D model for designing tool

Considering the warehouse infrastructure, two basic models of warehouse buildings were developed. As in the unity, the models can be rescaled to represent different building configurations. The same model was used for multiple configurations. As it can be seen in Figure 104, the models are highly optimized, with a small number of vertices to improve computational performance.

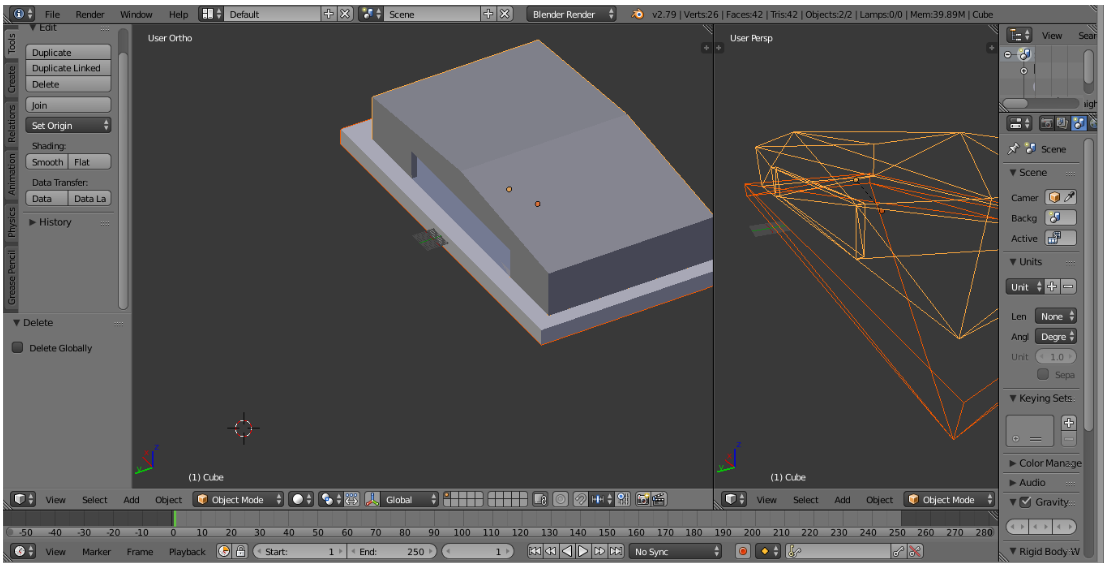


Figure 104: Optimized warehouse 3D model

To represent the transport demand generation, a basic infrastructure element (Figure 105) was adapted. All different transport demands use the same model; however, text elements are added for building different transport generation.

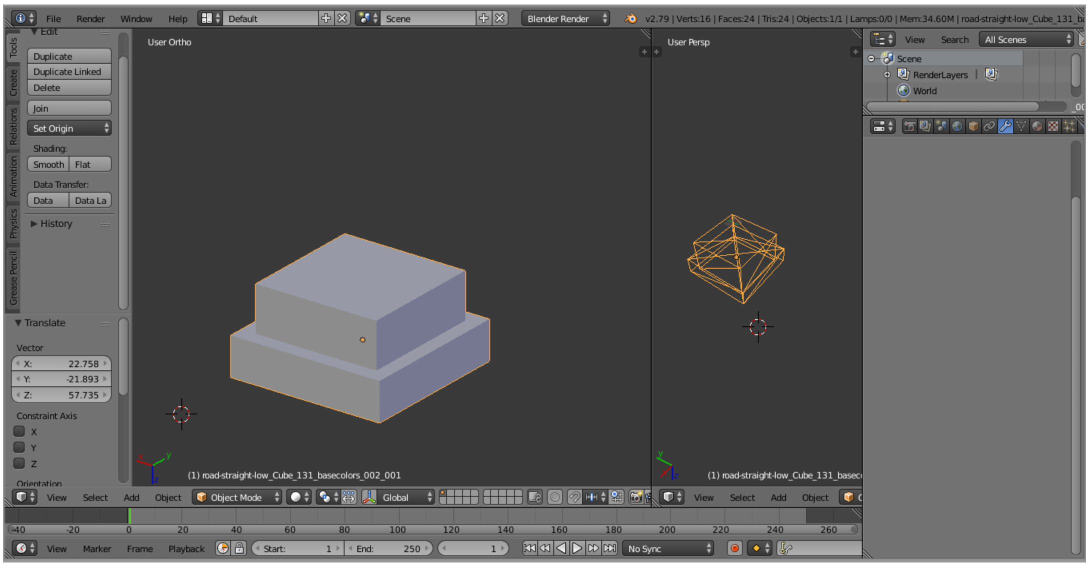


Figure 105: Transport Demand Generator (TG) 3d model

6.1.4 Scenario creation

For the scenario, creation of the first step required in the framework develop is the KPIs definition. The KPIs related to the scenario help to understand how the elements available for the user impact and are impacted by the KPIs. A high number of KPIs can be used simultaneously, depending on the characteristics of the interchange and the scenario. Figure 106 illustrates the KPIs selection (resource).

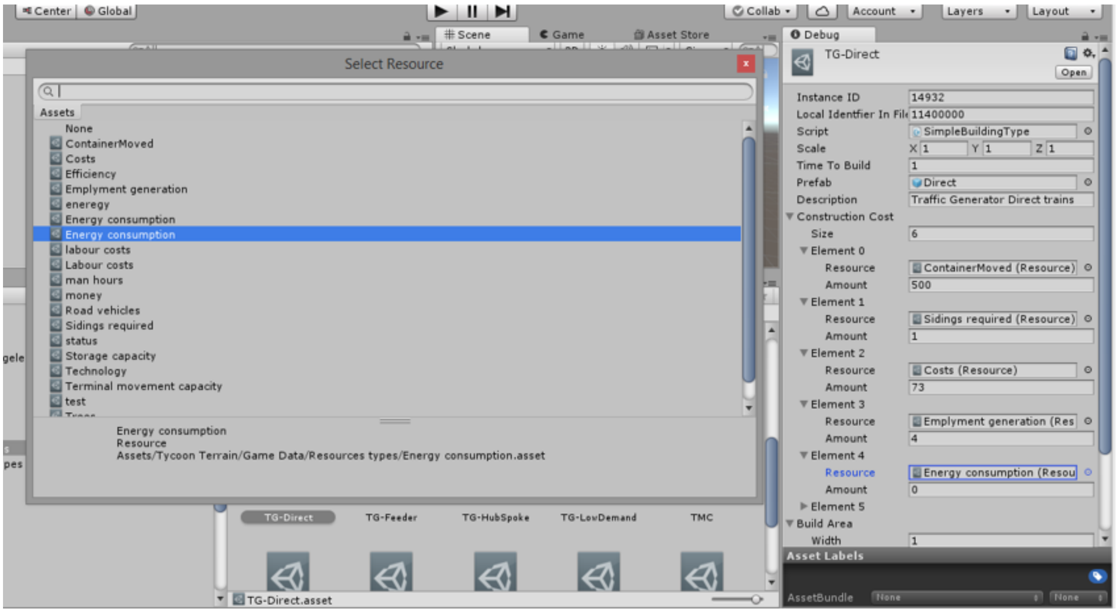


Figure 106: KPIs selection for interchange designing tool

The main KPIs selected to be used on the East Midland Interchange scenario were: costs (considering terminal operator viewpoint), storage capacity, lifting capacity, energy consumption, container moved, sidings required for the operation, employment generated (direct), road vehicles arriving the terminal, and trees planted. As it can be seen in Figure 107, all the KPIs started at zero.

Figure 107: KPIs values at beginning of the simulation

After selecting and placing a traffic generation (e.g., hub-spoke), the costs increase by the values assigned for the KPIs selected; for example, train operation, energy consumption, and jobs are generated, and siding is required (Figure 108). Now, for the new transport demand, a number of containers are required in the interchange; therefore, a container handling system needs to be deployed in the scenario.

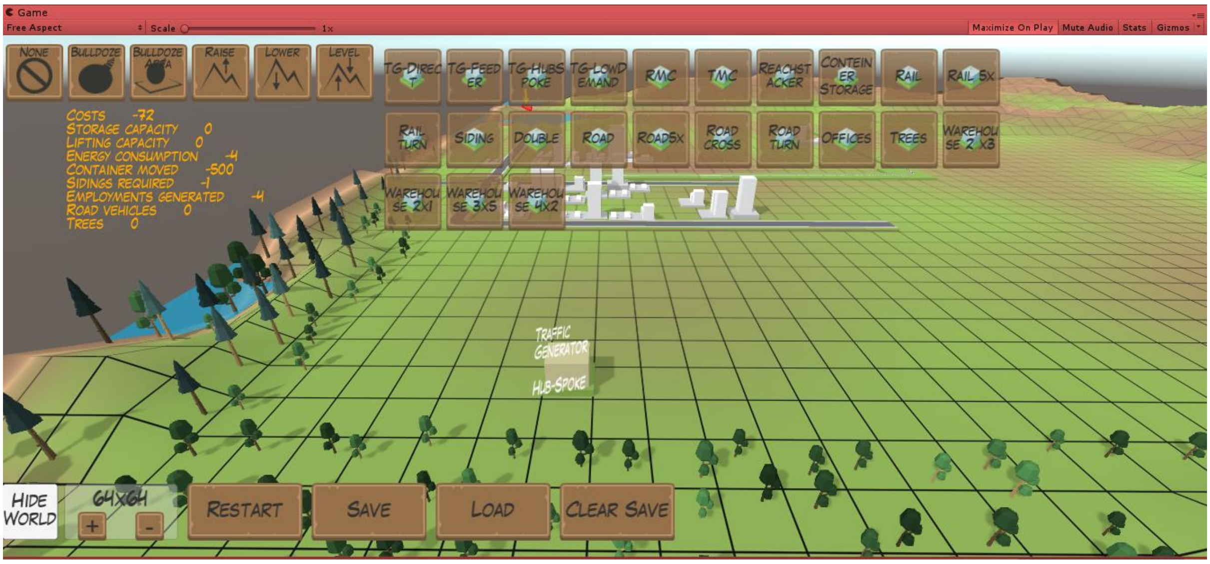


Figure 108: Traffic Demand Generator creation

Now, to lift the containers, the user needs to select and place the transhipment equipment in the map (Figure 109).

Figure 109: Lifting equipment's creation

After the lifting equipment (lifting capacity increased), a new warehouse infrastructure is required in the scenario to address the transport demand. As Figure 110 illustrates, the multiple warehouses can be deployed in the scenario, helping to meet the transport demand.

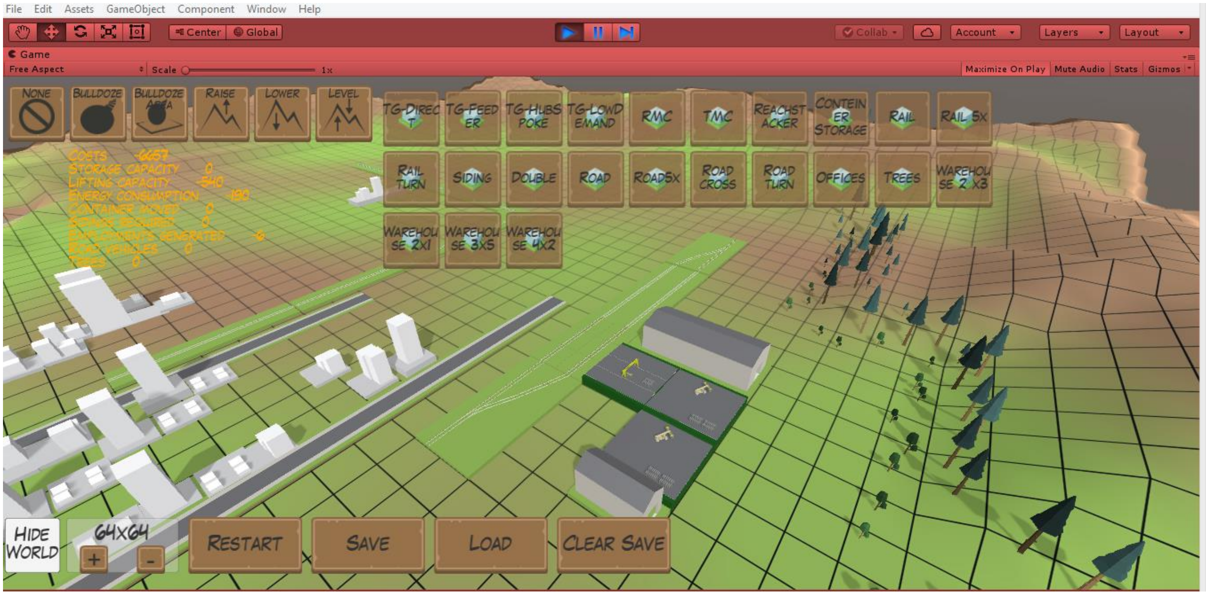


Figure 110: Warehouse development to address the container flow

As the example illustrates, the interchange equipment selected to be used in the scenario can influence multiples KPIS, enabling the user to understand the dynamic influence of the equipment deployed in the scenario.

6.1.5 Stakeholders Involved

The proposal submitted for the East Midland Interchange covers four main areas: Economic, Environmental, Social, and Operational. Therefore, to demonstrate the use of the software application for the multiple stakeholders, a similar stakeholder's structure was considered in the case study. Three different "decision profiles" were created to evaluate the impact of the preferences in the interchange decisions.

The priorities can be assigned considering the user priorities in the priorities matrix (Table 8) . To illustrate the difference between the decision profiles, different profiles were created to simulate preferences and the respective importance of each criteria. Considering the importance given by the National Planning Policy Framework to the economic benefits, the first priority "preference profile" (profile 1) created focuses on the rail performance.

Using the online implementation of the AHP developed in this thesis to compare the preferences, the user can modify the pairwise comparisons to identify the priorities. Table 8 illustrates a hypothetical implementation for profile 1.

Table 8: Priorities matrix- Profile 1

Priorities matrix - pairwise comparisons				
	Environmental	Employment	Performance	Economic costs
Environmental	Equal importance	Moderately more important	Very strongly less important	Strongly less important
Employment	Moderately less important	Equal importance	Extremely less important	Strongly less important
Performance	Very strongly more important	Extremely more important	Equal importance	loderately more important
Economic costs	Strongly more important	Strongly more important	Moderately less important	Equal importance

	Priority	Consistency
Environmental	0.094	3.18
Employment	0.049	3.74
Performance	0.584	4.11
Economic costs	0.273	3.85

(Spreadsheet available for editing at: https://docs.google.com/spreadsheets/d/1U41nAW6dT9hnGfEh0DDS4AXNkugdpMDH3Dr565Cc0xo/edit#gid=0

Considering the preferences assigned in table 8 the numeric value complete the table 9 according with AHP method and Saaty scale.

Table 9: Numeric values and calculations

fx =SUM(C10:C13)

	A	B	C	D	E	F	G
9			Environmental	Employment	Performance	Economic costs	
10		Environmental	1	3	0.14285	0.2	
11		Employment	0.33333	1	0.11111	0.2	
12		Performance	7	9	1	3	
13		Economic costs	5	5	0.33333	1	
14			13.33333	18	1.58729	4.4	
15							
16							
17			Environmental	Employment	Performance	Economic costs	Sum
18		Environmental	0.075	0.167	0.090	0.045	0.377
19		Employment	0.025	0.056	0.070	0.045	0.196
20		Performance	0.525	0.500	0.630	0.682	2.337
21		Economic costs	0.375	0.278	0.210	0.227	1.090

The sum of all values of the columns (e.g Environmental in the cell C14) is used to calculate the impact of the value against the total value, for example in the cell C18 the value assigned in the cell C10 is divided by the cell with the sum (C14)

With the sum of the total value of the lines (e.g C14 for Environmental) one can finally calculate the relative importance of the criteria, dividing the number found in cells G18 to G21) by the number of criterions. In this particular example 0,3777 by 4. The results of this process generate the priority matrix shown on table 6.

As it can be seen by the implementation, when the performance criteria have higher importance in the pairwise matrix, the priority value has higher impact on the criteria.

The second hypothetical preference profile (profile 2) focused on the environmental impact of the interchange and the importance given by the National Planning Policy Framework to the “good design” for national network infrastructure.

“produce sustainable infrastructure sensitive to place, efficient in the use of natural resources and energy used in their construction, matched by an appearance that demonstrates good aesthetics as far as possible”

Higher importance was given for environmental impact in the pairwise matrix as shown in table 10 The preference inputs introduced in the AHP tool can be edited through the link (https://docs.google.com/spreadsheets/d/1UDD1GzDHPT63_48NE35Ocov7b1vXjPIDmaAnMd0c8e0/edit?usp=sharing)

Table 10: Priorities matrix - Profile 2

Priorities matrix - pairwise comparisons				
	Environmental	Employment	Performance	Economic costs
Environmental	Equal importance	Very strongly more important	Moderately more important	Strongly more important
Employment	Very strongly less important	Equal importance	Moderately less important	Moderately less important
Performance	Moderately less important	Moderately more important	Equal importance	Equal importance
Economic costs	Strongly less important	Moderately more important	Equal importance	Equal importance

	Priority	Consistency
Environmental	0.585	4.08
Employment	0.066	4.18
Performance	0.184	4.19
Economic costs	0.164	4.22

For the third profile, the economic costs of the infrastructure and facilities were used as main criteria for the preferences. As result of the priorities introduced in the AHP tool, the priority matrix illustrated in table 11, a higher impact (54,5%) was calculated for the economic costs.

3 Profile- Economic costs

Table 11: Priorities matrix - Profile 3

Priorities matrix - pairwise comparisons	Environmental	Employment	Performance	Economic costs
Environmental	Equal importance	Moderately more important	Moderately less important	Extremely less important
Employment	Moderately less important	Equal importance	Moderately less important	Moderately less important
Performance	Moderately more important	Moderately more important	Equal importance	Moderately less important
Economic costs	Extremely more important	Moderately more important	Moderately more important	Equal importance

	Priority	Consistency
Environmental	0.127	2.36
Employment	0.096	3.65
Performance	0.232	3.24
Economic costs	0.545	3.85

6.1.6 Decision Drivers and Objective Function

Following the methodology developed, the KPIs and the performances of the functional blocks are measured online and the data can now be used offline to help identify the most suitable equipment, the objective functions were created according to the stakeholders' preferences. The decision-making process considered the technical characteristics of the different equipment options available. Is important to take into account that the costs of the various profiles can be dramatically different (e.g. taxes and social cost should be not considered in Societal profiles)

In order to exemplify the method developed, the investments decisions for an interchange were analysed considering lifting equipment and the warehouse. For the lifting equipment, four main variables were considered: costs, employment generations, movement capacity, and energy consumption. Table 12 illustrates the value of the different equipment and average value.

Table 12: Lifting equipment's KPIs

Buildings	ReachStacker	Rail mounted crane	Tyre mounted crane	Avarage
Resources				
Costs	£850,000.00	£2,000,000.00	£1,700,000.00	£1,516,666.67
Employment generation	2	2	2	2
Terminal movement capacity	120	300	200	206.6666667
Energy consumption (day)	80	30	40	50

The calculation of efficiency value and constrain value of each element can be determined by the formula:

$$Eff_V = \sum_{i}^{N} (Pri_v\,(i).\,(\frac{V_{cost}}{V_{avar}}))$$

Where

Effv = Efficiency value for the objective function considering the user priority

Priv = Priority weighed by the AHP module

Vcost = Value assigned for each KPI (e.g. employment generation)

Vavar = Average value of the KPI

Similarly, the constrain value can be calculated by the formula

$$Const_V = \sum_{i}^{N} (Pri_v\,(i).\,(\frac{C_{cost}}{C_{avar}}))$$

Constv = Constrain value for subject the objective function considering the user priority

Priv = Priority weighed by the AHP module

Vcost = Value assigned for KPIs that constrain the optimization (e.g. costs)

Vavar = Average value of the KPI

As can be seen in table 13 the efficiency value of the Reach Stacker is given by the priority of environmental (cell H30) multiplied by the terminal movement energy consumption plus the employment priority criteria (cell H31) by the relative employment generation plus the performance criteria multiplied the terminal capacity (cell J24)

Table 13: Spreasheet details

=(H30*J25+J21*H31+J24*H32)*100

G	H	I	J	K	L	M
Road Traffic Gen		Buildings	ReachStacker	Rail mounted crane	Tyre mounted crane	Avarage
		Resources				
1		Conteineres moved				
25		Conteineres moved (month)				
0		Sidings requireds				
432		Costs	£850,000.00	£2,000,000.00	£1,700,000.00	£1,516,
2		Employment generation	2	2	2	
210		Energy consumption (day)	80	30	40	
		Profile1	ReachStacker	Rail mounted crane	Tyre mounted crane	
		Conteineres moved				
		Conteineres moved (month)				
		Sidings requireds				
		Costs	56.04%	131.87%	112.09%	
		Employment generation	100.00%	100.00%	100.00%	
		Road Vehicles				
		Trees				
		Terminal movement capacity	58.06%	145.16%	96.77%	
		Energy consumption (day)	-16.00%	-6.00%	-8.00%	
		Storage capacity				
		Storage area(sqr meter)				
		Efficiency Value	=(H30*J25+J21*H31+J24*H32)*100		61	
	Priorities	Constrain Value	15	36	31	
Environmental	0.094		ReachStacker	Rail mounted crane	Tyre mounted crane	
Employment	0.049	Profile 2	8	30	20	
Performance	0.584	Efficiency Value	9	22	18	
Economic costs	0.273	Cost Value	ReachStacker	Rail mounted crane	Tyre mounted crane	
		Profile 3	21	42	31	
		Efficiency Value	31	72	61	
		Cost Value				

The efficiency value and constrain value for the 3 profiles are shown in table 14.

Table 14: Efficiency value and constrain values for the three profiles

Profile1	ReachStacker	Rail mounted crane	Tyre mounted crane
Efficiency Value	37	89	61
Constrain Value	15	36	31
Profile 2	ReachStacker	Rail mounted crane	Tyre mounted crane
Efficiency Value	8	30	20
Cost Value	9	22	18
Profile 3	ReachStacker	Rail mounted crane	Tyre mounted crane
Efficiency Value	21	42	31
Cost Value	31	72	61

6.1.7 GA Application

6.1.7.1 Selecting Transhipment/Lifting Equipment

As presented in the previous chapter, the genetic algorithm (GA) is a search heuristic used to generate solutions to optimize and search problems that mimic the process of natural selection.

For the GA package initialization, a population size needs to be assigned, depending on the nature of the problem. For this case study, the values assigned in the previous section ("efficiency value" and "constrain value") were used to create a generic representation of the options. In order to exemplify the GA module for the lifting equipment, a 12-gene representation was developed consisting of 4 genes for each option as shown in Table 15.

Table 15: Gene representation

		Reach Stacker				Rail mouted Crane				Tyre mounted crane			
	Gene	1	2	3	4	5	6	7	8	9	10	11	12
Profile 1	EfficiencyValue	37	37	37	37	89	89	89	89	61	61	61	61
Lifting Equipment	ConstrainValue	15	15	15	15	36	36	36	36	31	31	31	31
Profile 2	EfficiencyValue	8	8	8	8	30	30	30	30	20	20	20	20
Lifting Equipment	ConstrainValue	9	9	9	9	22	22	22	22	18	18	18	18
Profile 3	EfficiencyValue	21	21	21	21	42	42	42	42	31	31	31	31
Lifting Equipment	ConstrainValue	31	31	31	31	72	72	72	72	61	61	61	61

A theoretical solution with a value 1 in all genes (binary code) represents a solution with four reach stackers, four Rail mounted Crane, and four Tyre mounted Crane. To identify the "best" transshipment equipment configuration, the software was implemented with the setup considering a initial population of 30 individuals, a maximum constrain value of 220 and a stop criteria of three generation without changes or maximum of 300 generations. A probability of 50% crossover and 5% for mutation was assigned as shown in Figure 111.

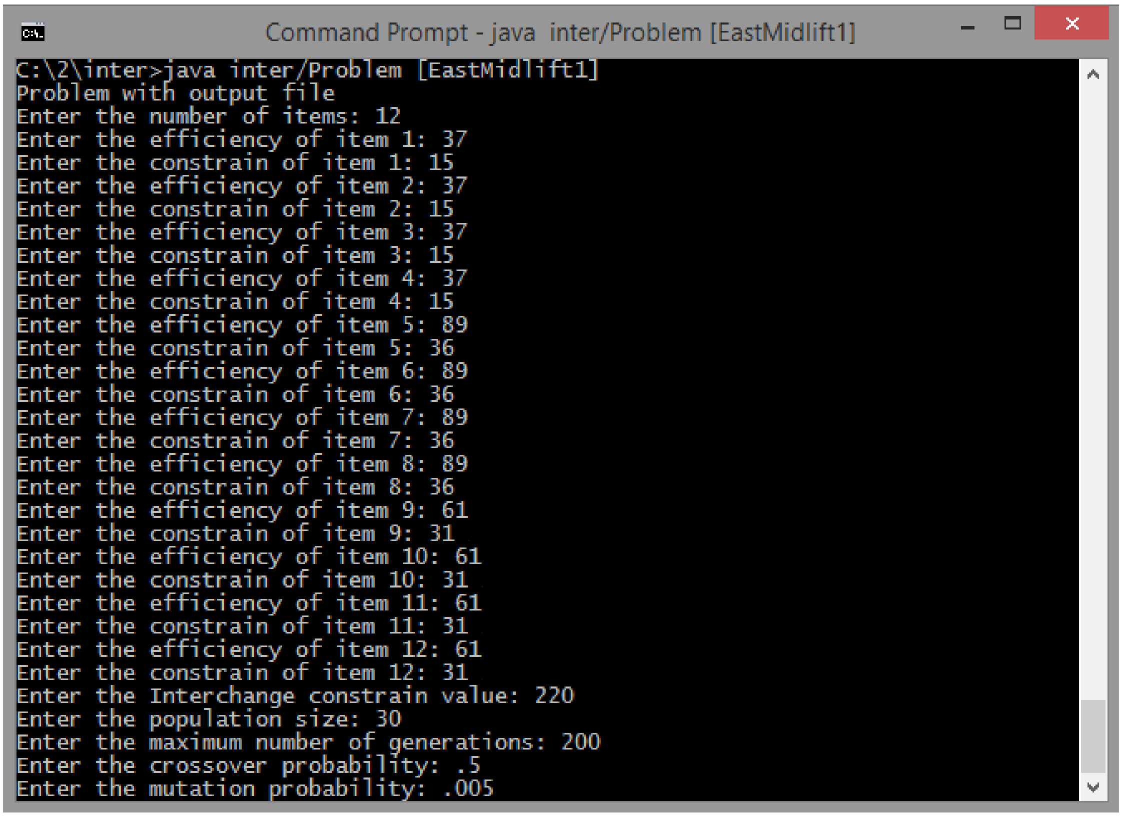


Figure 111: GA implementation for lifting decision - Profile 1

Following the execution, the stop criteria were reached after 51 generations, and the optimal list of equipment to the interchange includes the options 1,2,4,5,6,7,8 and 11. The evolution of the mean fitness of the solution (efficiency value) is shown in Figure 113.

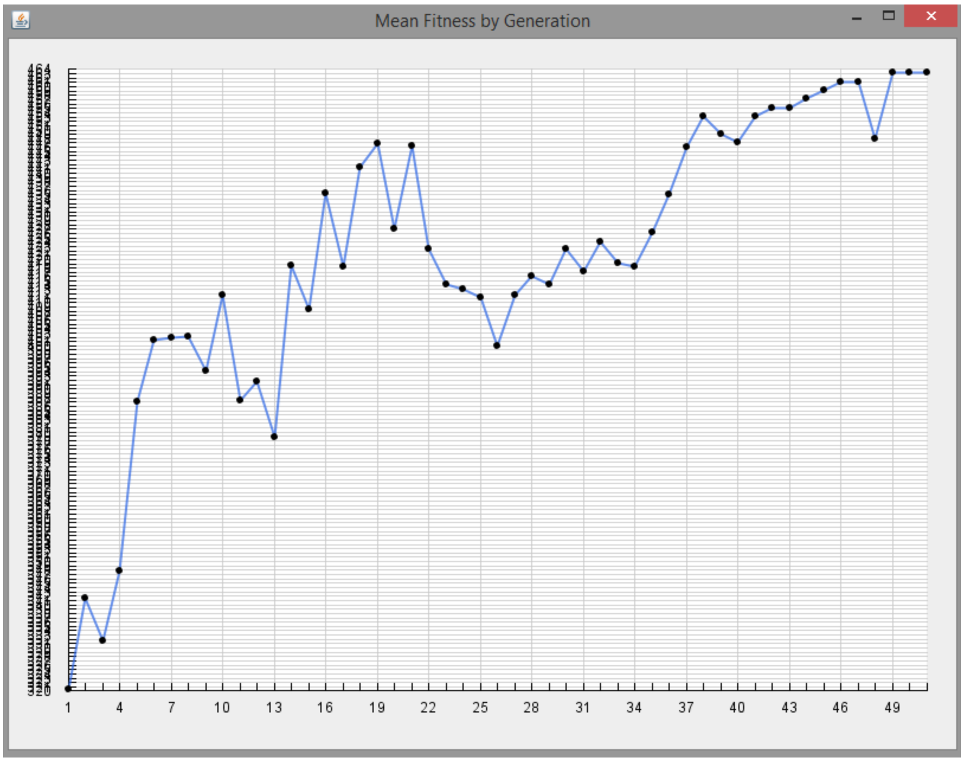


Figure 112: Mean evolution for lifting decision - Profile 1

For the second profile, the same criteria were applied as shown in Figure 113.

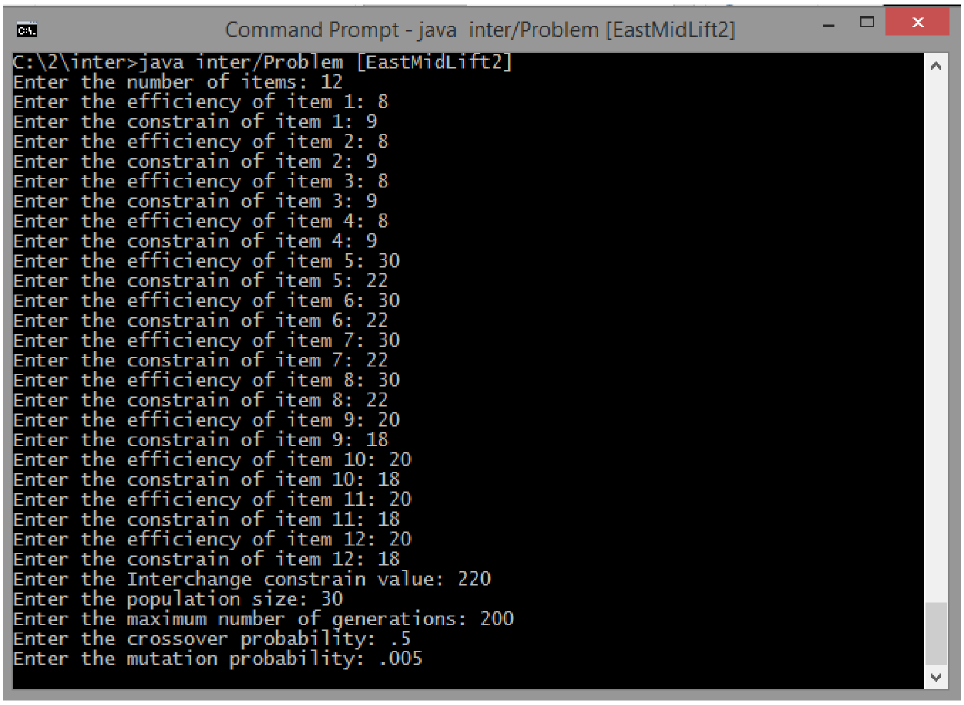


Figure 113: GA implementation for lifting decision - Profile 2

The stop criteria were reached at generation 47, however by the little importance given to cost in profile 2, the maximum cost possible lowe than cost constrain, therefore the algorithm was able to select all twelve equipment (gen 11111111111). For a real case scenario, additional genes or reduction on maximum constrain value are recommended. Figure 114 illustrates the growth of the mean fitness over the generations.

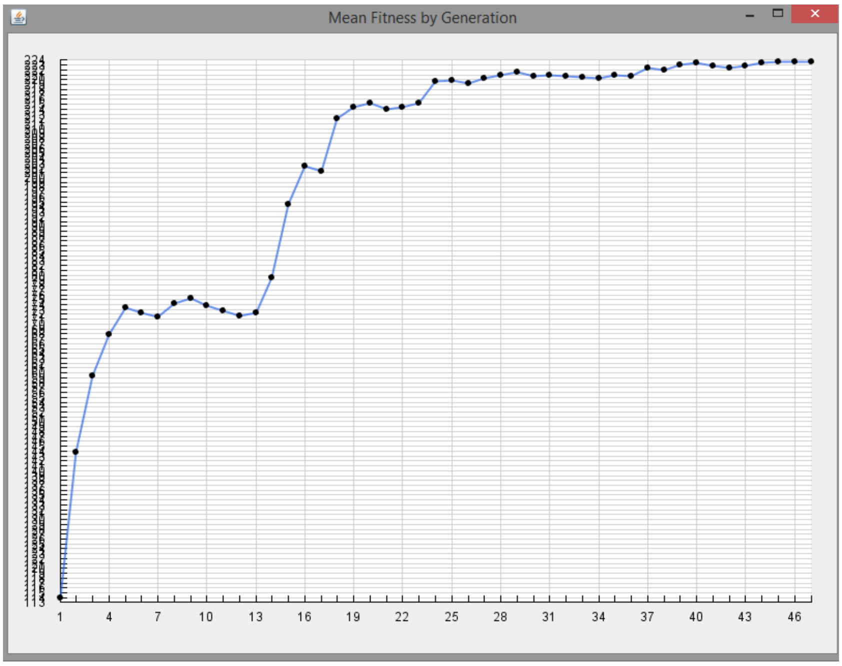


Figure 114: Mean evolution for lifting decision - Profile 2

The same values are also used for profile 3 as illustrated in Figure 115.

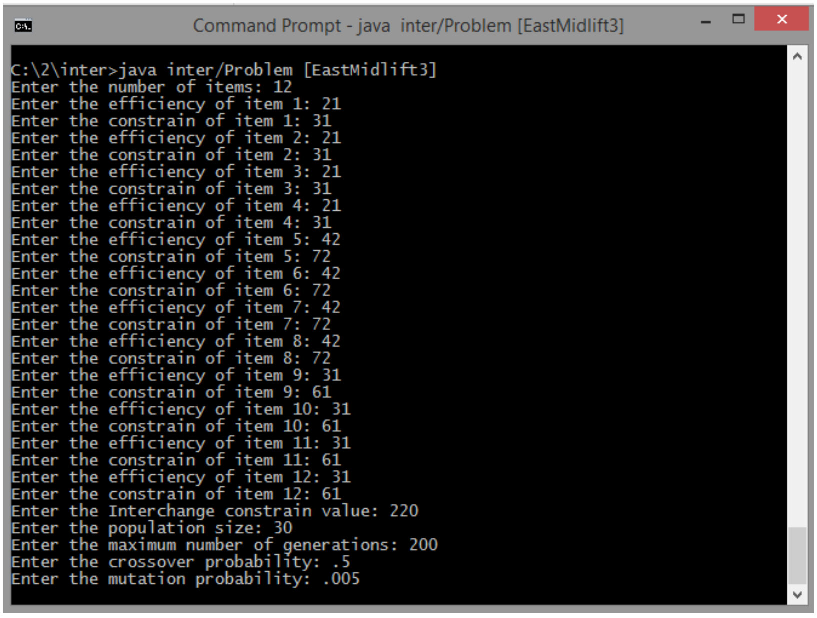


Figure 115: GA implementation for lifting decision - Profile 3

Due to the importance given by the costs on profile 3 (54%), the values of the individual constraints of the alternatives are significantly higher; therefore, the number of the equipment selected is lower. After 67 generations, the algorithm selected the options 2, 3, 6 and 12. Figure 116 shows the mean fitness evolution.

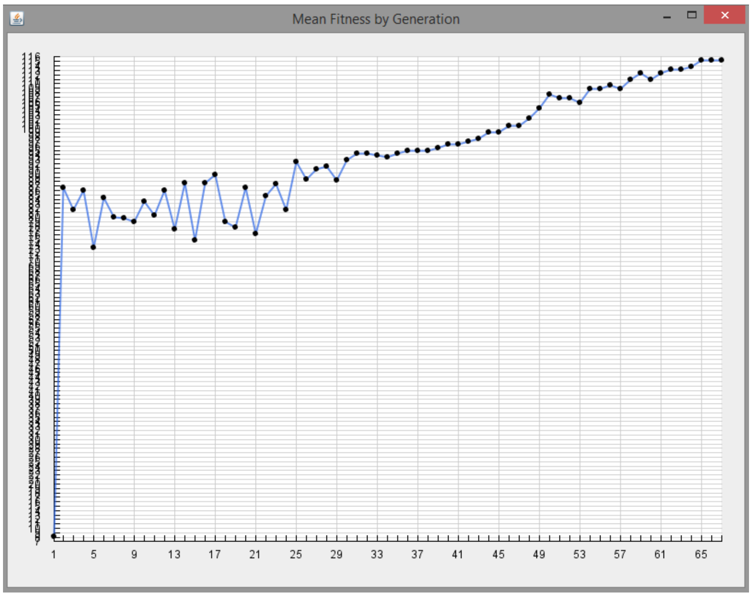


Figure 116: Mean evolution for lifting decision - Profile3

Considering the three different profiles, the reach stacker genes were selected 67% of the time, rail mounted crane 75%, and the tyre mounted crane 50%.

In the designer application, KPIs related to the cost of lifting equipment, energy consumption, employment, and movement are created using the values previously assigned for the lifting elements. The creation of additional KPI or adjustment on the value of the assigned can be made on the KPIs' options (Resource type on the interchange designer) as illustrated in Figure 117.

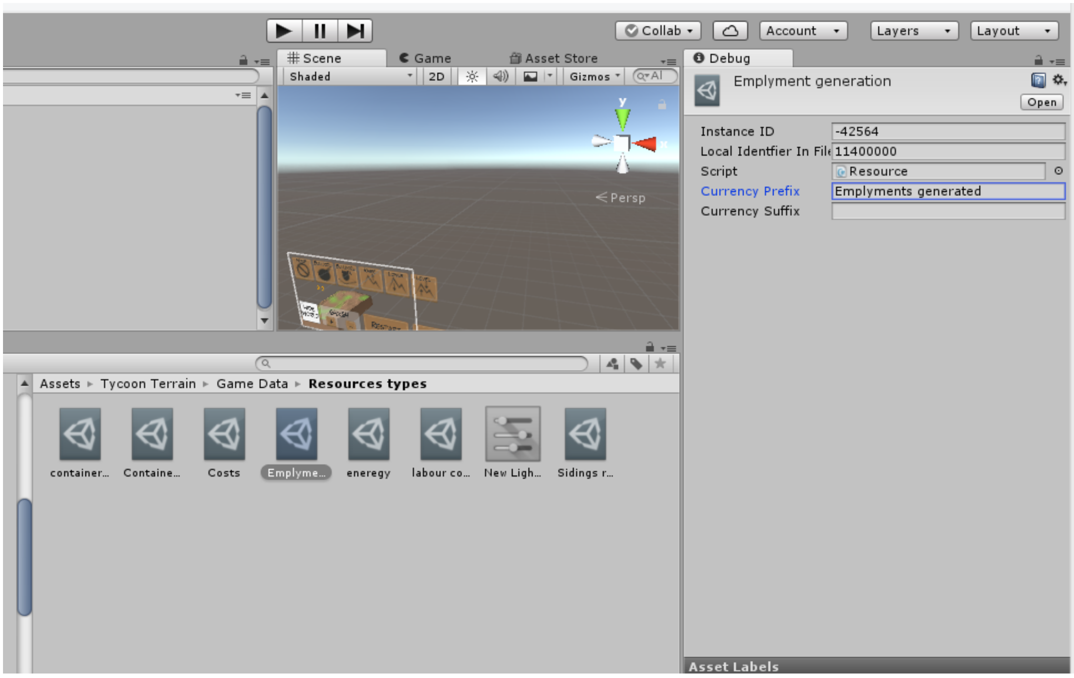


Figure 117: Additional KPIs creation

6.1.7.2 Selecting Warehouse

The warehouse facilities simulated based on the total are occupied by the buildings; the 500£ per square meter value is used to estimate the cost of the building. The capacity of the building is based on the area available in the building. On the evaluations, four different buildings are created. Table 12 illustrates the warehouse options and the main variables used.

Table 16: Warehouse costs

	blocks	Sqr meter	Cost sqr meter	Total cost	Containercapacity
Warehouse 2x3	6	15000	500	£7,500,000.00	19350
Warehouse 2x1	2	5000	500	£2,500,000.00	6450
Warehouse 2x4	8	20000	500	£10,000,000.00	25800
Warehouse 3x5	15	37500	500	£18,750,000.00	48375

Figure 118 shows the 3D model assigned for one of the warehouse units. As it can be seen, the building occupies two squares in the terrain.

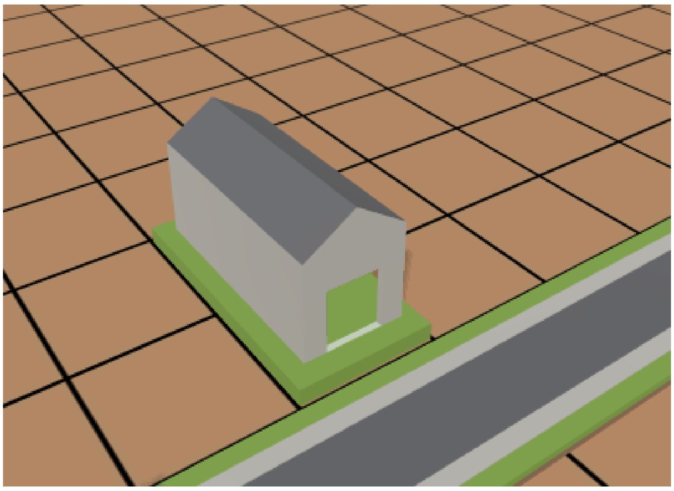


Figure 118: Warehouse placement

Using the same method used for the lifting equipment, the warehouse options are classified using the follow variables in table 17.

Table 17: Warehouse KPIs

Buildings	Warehouse2x3	Warehouse2x1	Warehouse4x2	Warehouse3x5	Avarage
Costs	£7,500,000.00	£2,500,000.00	£10,000,000.00	£18,750,000.00	£9,687,500.00
Employment generation	4	3	4	5	4
Energy consumption (day)	150	100	200	300	187.5
Storage capacity	375	125	500	935	483.75
Storage area(sqr meter)	15000	5000	20000	37500	19375

Table 18 illustrates the efficiency value and constrain values calculated for the three decision profiles.

Table 18: Efficiency and constrain values

Profile1	Warehouse2x3	Warehouse2x1	Warehouse4x2	Warehouse3x5
Efficiency Value	49	18	64	118
Constrain Value	21	7	28	53
Profile 2				
Efficiency Value	16	7	19	35
Cost Value	13	4	17	32
Profile 3				
Efficiency Value	27	13	32	55
Cost Value	42	14	56	106

To illustrate the capacity of the software for handling more complex scenarios, we represent the warehouse decision in 40 genes as shown in table 15. A population consisting of 500 individuals was used and a maximum of 300 generations as stop criteria. A value of 500 was assigned as maximum generation and the same crossover and mutation values used previously.

Table 19: Warehouse decision using 40 Genes representation - Profile 1

		Warehouse 2x3									
	Gene	1	2	3	4	5	6	7	8	9	10
Profile 1	EfficiencyValue	49	49	49	49	49	49	49	49	49	49
Warehouse	ConstrainValue	21	21	21	21	21	21	21	21	21	21
		Warehouse 2x1									
	Gene	11	12	13	14	15	16	17	18	19	20
Profile 1	EfficiencyValue	18	18	18	18	18	18	18	18	18	18
Warehouse	ConstrainValue	7	7	7	7	7	7	7	7	7	7
		Warehouse 4x2									
	Gene	21	22	23	24	25	26	27	28	29	30
Profile 1	EfficiencyValue	64	64	64	64	64	64	64	64	64	64
Warehouse	ConstrainValue	28	28	28	28	28	28	28	28	28	28
		Warehouse 3x5									
	Gene	31	32	33	34	35	36	37	38	39	40
Profile 1	EfficiencyValue	55	55	55	55	55	55	55	55	55	55
Warehouse	ConstrainValue	106	106	106	106	106	106	106	106	106	106

The calculation takes six seconds, and the best options to include in the Interchange are the genes: 1 2 3 4 5 6 7 9 10 12 13 14 15 17 18 19 20 21 22 23 24 26 27 28 29 and 30.

Figure 120 illustrates the evolution of the mean fitness.

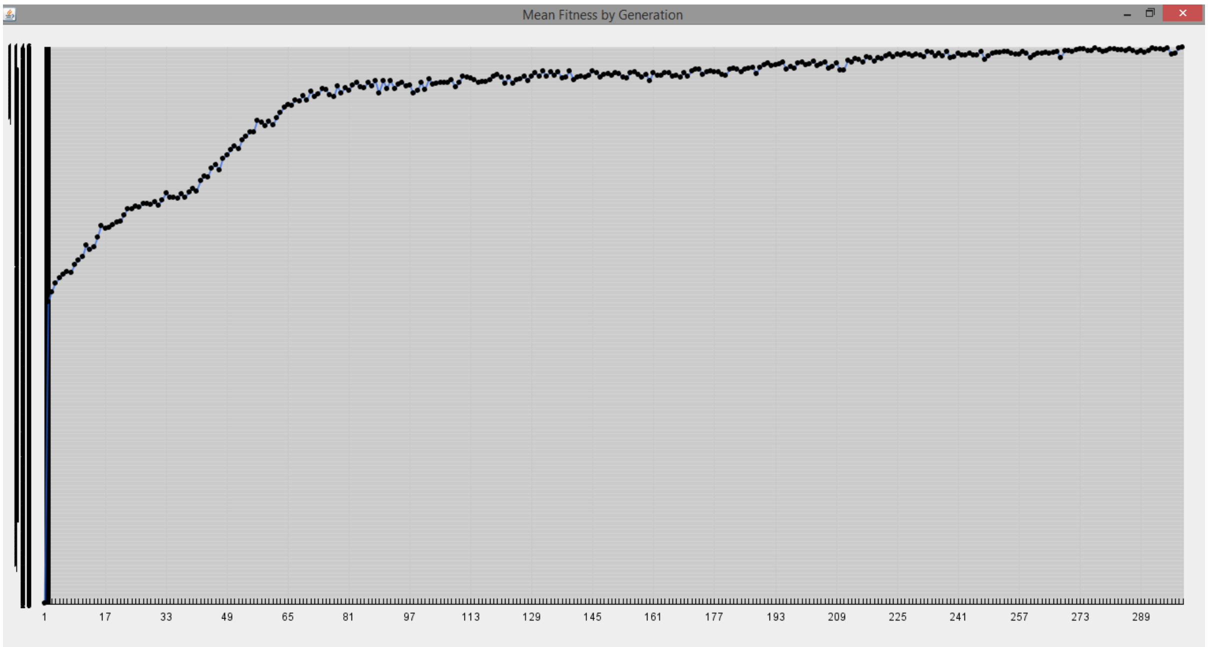


Figure 119: Mean efficiency evolution - 300 Generations- Profile 1

The same values were used for profile 2 as illustrated in table 20.

Table 20: Warehouse decision using 40 Genes representation - Profile 2

		Warehouse 2x3									
	Gene	1	2	3	4	5	6	7	8	9	10
Profile 2	EfficiencyValue	16	16	16	16	16	16	16	16	16	16
Warehouse	ConstrainValue	13	13	13	13	13	13	13	13	13	13
		Warehouse 2x1									
	Gene	11	12	13	14	15	16	17	18	19	20
Profile 2	EfficiencyValue	7	7	7	7	7	7	7	7	7	7
Warehouse	ConstrainValue	4	4	4	4	4	4	4	4	4	4
		Warehouse 4x2									
	Gene	21	22	23	24	25	26	27	28	29	30
Profile 2	EfficiencyValue	19	19	19	19	19	19	19	19	19	19
Warehouse	ConstrainValue	17	17	17	17	17	17	17	17	17	17
		Warehouse 3x5									
	Gene	31	32	33	34	35	36	37	38	39	40
Profile 2	EfficiencyValue	35	35	35	35	35	35	35	35	35	35
Warehouse	ConstrainValue	32	32	32	32	32	32	32	32	32	32

For the second profile, the optimal list of items to include in the Interchange are :1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 26 27 28 31 33 34 36 37 38 and 39. Figure 120 shows the evolution of the mean fitness of the example.

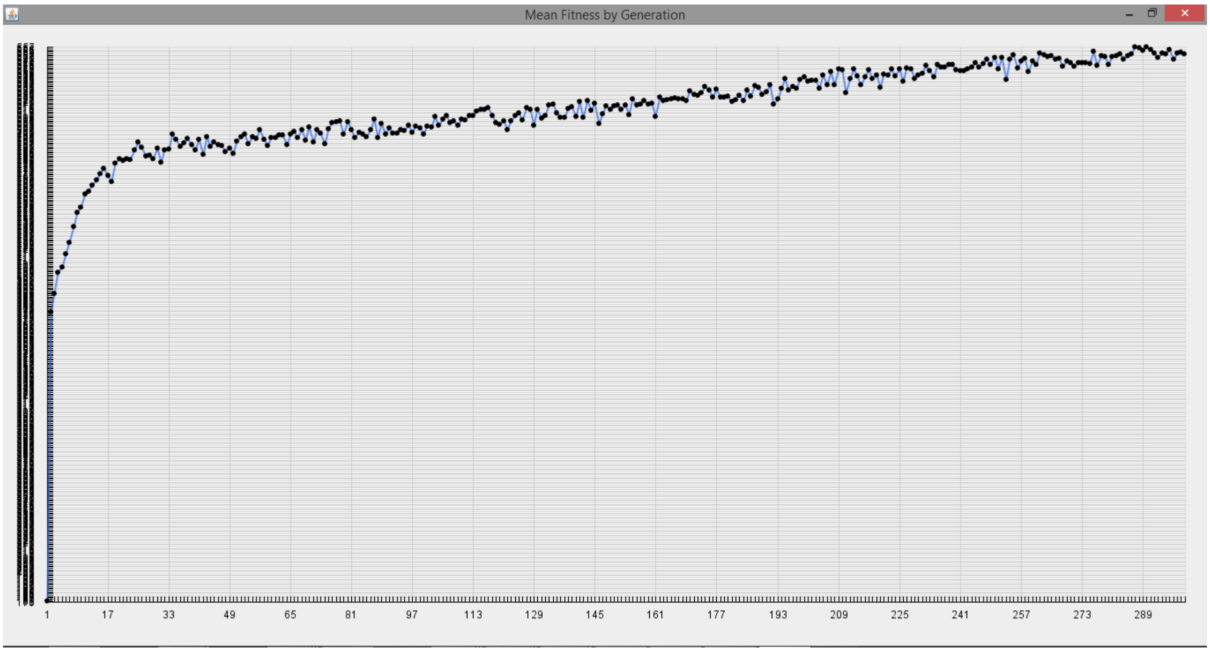


Figure 120: Mean efficiency evolution - 300 Generations- Profile 2

For profile 3, the previous steps were followed, and the values used are presented in table 21.

Table 21: Warehouse decision using 40 Genes representation - Profile 3

		Warehouse 2x3									
	Gene	1	2	3	4	5	6	7	8	9	10
Profile 3	EfficiencyValue	27	27	27	27	27	27	27	27	27	27
Warehouse	ConstrainValue	42	42	42	42	42	42	42	42	42	42
		Warehouse 2x1									
	Gene	11	12	13	14	15	16	17	18	19	20
Profile 3	EfficiencyValue	13	13	13	13	13	13	13	13	13	13
Warehouse	ConstrainValue	14	14	14	14	14	14	14	14	14	14
		Warehouse 4x2									
	Gene	21	22	23	24	25	26	27	28	29	30
Profile 3	EfficiencyValue	35	35	35	35	35	35	35	35	35	35
Warehouse	ConstrainValue	56	56	56	56	56	56	56	56	56	56
		Warehouse 3x5									
	Gene	31	32	33	34	35	36	37	38	39	40
Profile 3	EfficiencyValue	55	55	55	55	55	55	55	55	55	55
Warehouse	ConstrainValue	106	106	106	106	106	106	106	106	106	106

The warehouse selected to be included in the Interchange are: 2 3 11 15 17 18 19 20 23 24 28 30 31. The evolution of the mean fitness is presented in Figure 121.

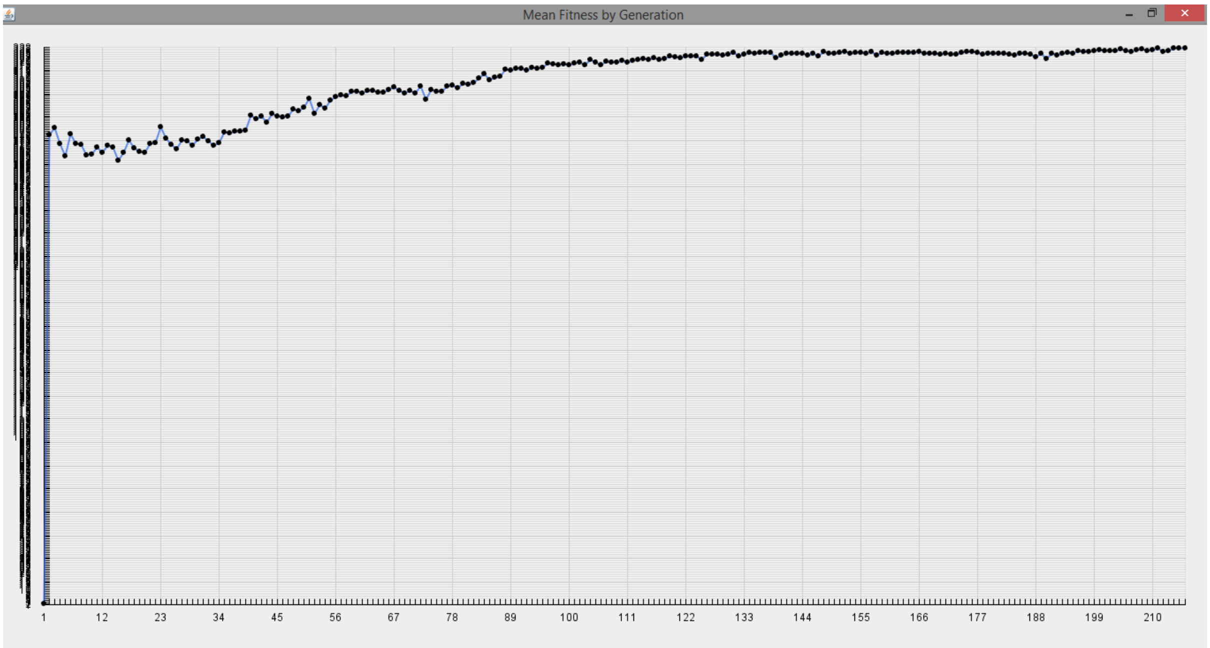
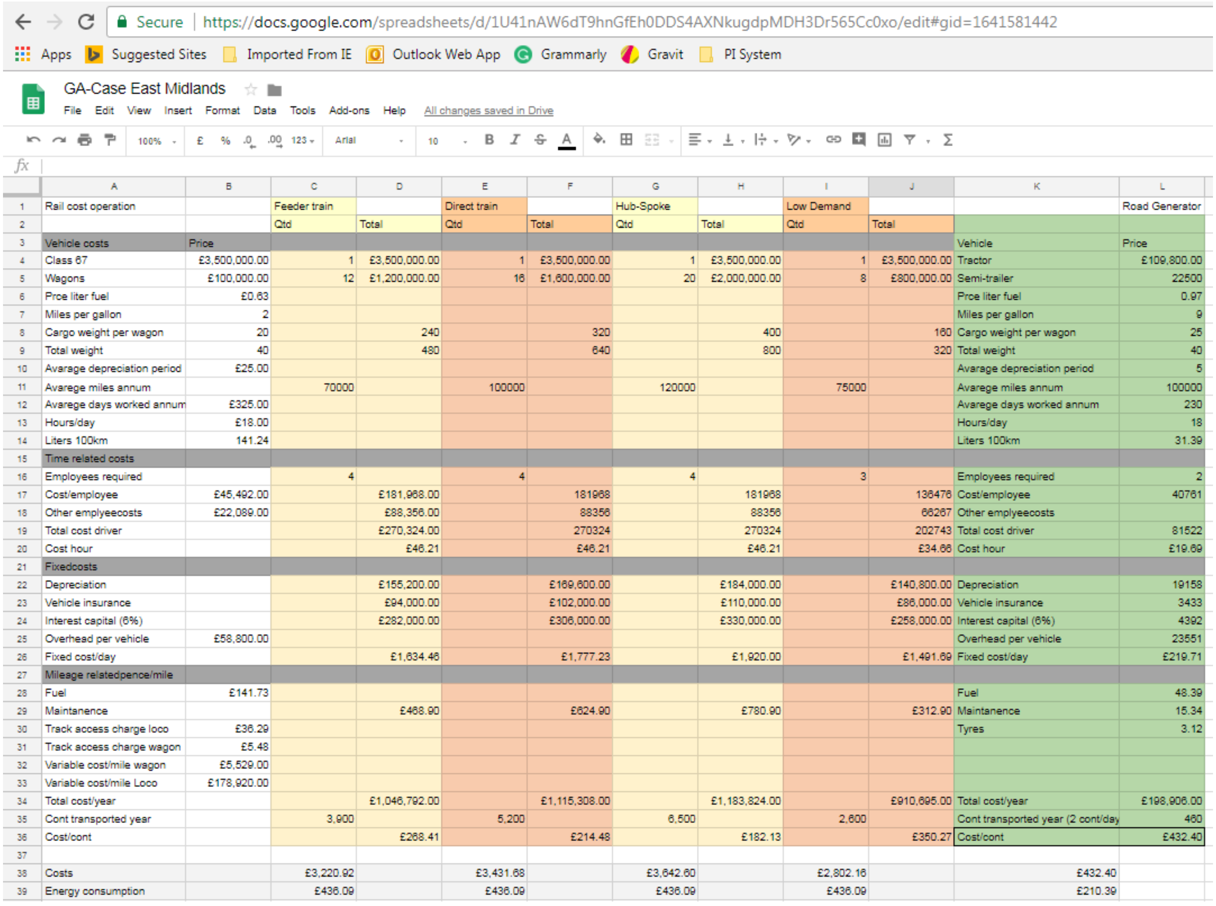


Figure 121: Mean efficiency evolution - 300 Generations- Profile 3

6.1.8 Operating Pattern

Considering that the main cargo transported on the SLPEMG will be the containerized goods, the operation patterns available for this scenario will accept Hub spoke generation, direct train, and dynamic routes for the train generator function.

Several datasets have been used for modelling the traffic generation characteristics (Figure 122); however, the values might be different in particular cases. To address this issue, the values can be modified in the spreadsheet to represent the costs and other variables.



	A	B	C	D	E	F	G	H	I	J	K	L
1	Rail cost operation		Feeder train		Direct train		Hub-Spoke		Low Demand			Road Generator
2			Qtd	Total	Qtd	Total	Qtd	Total	Qtd	Total		
3	Vehicle costs	Price									Vehicle	Price
4	Class 67	£3,500,000.00	1	£3,500,000.00	1	£3,500,000.00	1	£3,500,000.00	1	£3,500,000.00	Tractor	£109,800.00
5	Wagons	£100,000.00	12	£1,200,000.00	16	£1,600,000.00	20	£2,000,000.00	8	£800,000.00	Semi-trailer	22500
6	Prce liter fuel	£0.63									Prce liter fuel	0.97
7	Miles per gallon	2									Miles per gallon	9
8	Cargo weight per wagon	20		240		320		400		160	Cargo weight per wagon	25
9	Total weight	40		480		640		800		320	Total weight	40
10	Avarage depreciation period	£25.00									Avarage depreciation period	5
11	Avarege miles annum		70000		100000		120000		75000		Avarege miles annum	100000
12	Avarege days worked annum	£325.00									Avarege days worked annum	230
13	Hours/day	£18.00									Hours/day	18
14	Liters 100km	141.24									Liters 100km	31.39
15	Time related costs											
16	Employees required		4		4		4		3		Employees required	2
17	Cost/employee	£45,492.00		£181,968.00		181968		181968		136476	Cost/employee	40761
18	Other emplyeecosts	£22,089.00		£88,356.00		88356		88356		66267	Other emplyeecosts	
19	Total cost driver			£270,324.00		270324		270324		202743	Total cost driver	81522
20	Cost hour			£46.21		£46.21		£46.21		£34.66	Cost hour	£19.69
21	Fixedcosts											
22	Depreciation			£155,200.00		£169,600.00		£184,000.00		£140,800.00	Depreciation	19158
23	Vehicle insurance			£94,000.00		£102,000.00		£110,000.00		£86,000.00	Vehicle insurance	3433
24	Interest capital (6%)			£282,000.00		£306,000.00		£330,000.00		£258,000.00	Interest capital (6%)	4392
25	Overhead per vehicle	£58,800.00									Overhead per vehicle	23551
26	Fixed cost/day			£1,634.46		£1,777.23		£1,920.00		£1,491.69	Fixed cost/day	£219.71
27	Mileage relatedpence/mile											
28	Fuel	£141.73									Fuel	48.39
29	Maintanence			£468.90		£624.90		£780.90		£312.90	Maintanence	15.34
30	Track access charge loco	£36.29									Tyres	3.12
31	Track access charge wagon	£5.48										
32	Variable cost/mile wagon	£5,529.00										
33	Variable cost/mile Loco	£178,920.00										
34	Total cost/year			£1,046,792.00		£1,115,308.00		£1,183,824.00		£910,695.00	Total cost/year	£198,906.00
35	Cont transported year		3,900		5,200		6,500		2,600		Cont transported year (2 cont/day	460
36	Cost/cont			£268.41		£214.48		£182.13		£350.27	Cost/cont	£432.40
37												
38	Costs		£3,220.92		£3,431.68		£3,642.60		£2,802.16		£432.40	
39	Energy consumption		£436.09		£436.09		£436.09		£436.09		£210.39	

Figure 122: Traffic generator calculations

The spreadsheet is available at the link: https://docs.google.com/spreadsheets/d/1U41nAW6dT9hnGfEh0DDS4AXNkugdpMDH3Dr565Cc0xo/edit?usp=sharing

For the interchange designer tool, the main KPIs assigned for the traffic generators are presented in table 22.

Table 22: Traffic generators KPIs

Buildings	HUB generator	Direct link Gen	Feeder generator	LowDemand generator	Road Traffic Gen
Resources					
Conteineres moved	20	16	12	8	1
Conteineres moved (month)	500	400	300	200	25
Sidings requireds	1	1	1	1	0
Costs	3642	3431	3220	2802	432
Employment generation	4	4	4	3	2
Energy consumption (day)	436	436	436	436	210

6.1.9 Evaluation

Based on the values assigned for the infrastructure and the priorities defined in the AHP module, the GA module suggested three configurations for the East Midland Interchange as shown in table 23.

Table 23: Profiles comparison

	Profile 1	Profile 2	Profile 3
Warehouse 2 x3	9	9	2
Warehouse 2 x1	9	10	5
Warehouse 4x 3	9	8	3
Warehouse 3 x 5	0	3	1
Reachstackers	3	4	2
Tyre mounted Cranes	4	4	1
Rail mounted cranes	0	4	1
Total warehouse cost	£ 180,000,000.00	£ 228,750,000.00	£ 76,250,000.00
Total warehouse capacity	238,500.00	336,000.00	125,500.00
Total transhipment cost	£ 9,350,000.00	£ 18,200,000.00	£ 5,400,000.00

The final step is the implementation of the suggested layout, following the GA module recommendations, clicking in the infrastructure icons, and placing in the canvas. The East Midland Interchange scenario implementation was created to help understand the scenario creation process in the software packages. The designing tool enables inexperienced users to design the layout proposed on the masterplan or alternative layout and assess the impact of the infrastructure Figure 123 illustrates the profile 3 scenario layout.

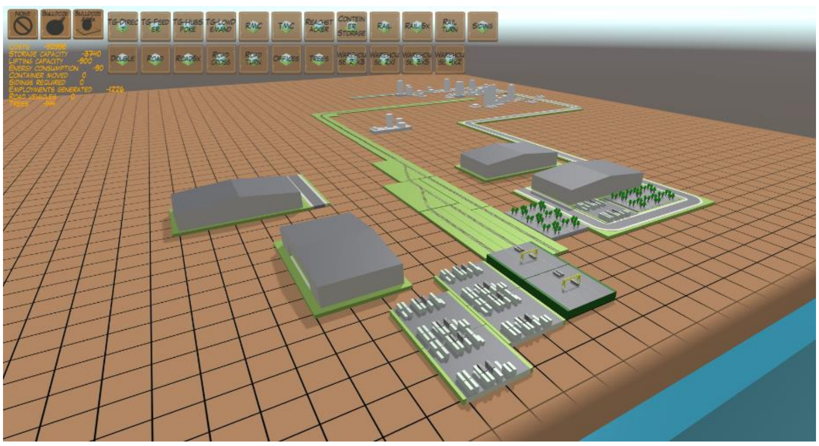


Figure 123: profile 3 scenario layout

6.2 Case Study 2: Physical Internet Interchange

6.2.1 Introduction

Recent research on Physical Internet concept (Pi) proposes a logistic interconnection between operators, comparing the logistic problems to digital interconnectivity (encapsulation, interfaces and protocols).

The goals are increasing the efficiency of the logistic system and "transforming the way physical objects are handled, moved, stored, realized, supplied and used, aiming towards global logistics efficiency and sustainability" (Montreuil 2011). According to Montreuil, the proportion of truck kilometres travelled without cargo in UK in 2004 was in order of 27%. And even when the travel was loaded, the weight capacity used was only 60%.

With Pi concept, the freight flows can be merged within new PI logistics networks to increase efficiency. Figure 124 illustrates PI networks and structure.

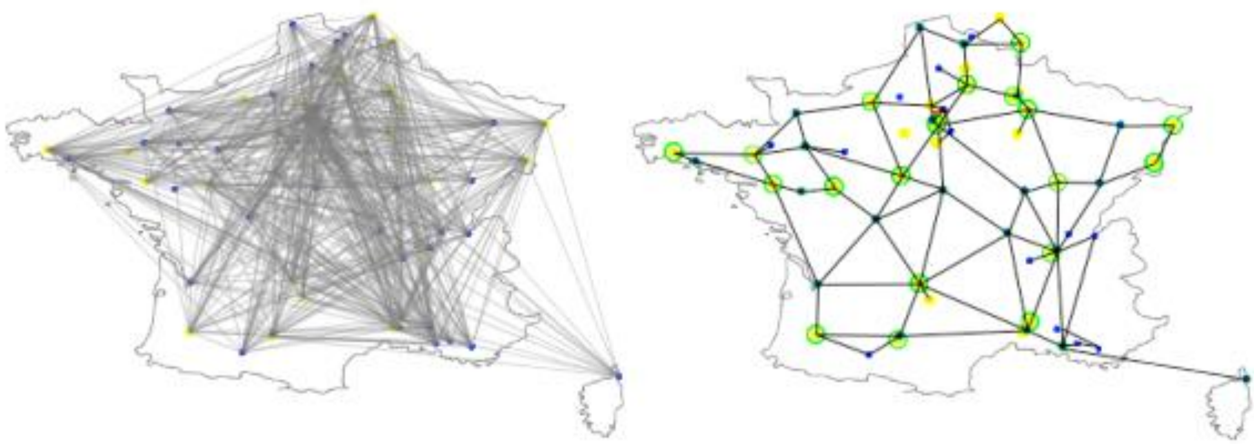


Figure 124: Flow merged comparison

The Pi Interchange scenario aims to use illustration software applications for designing and evaluating innovative concepts. Therefore, this case study implements a Physical Internet interchange scenario with the innovative elements for cargo transfer to illustrate how the designing tool can be adapted to simulate future scenarios.

To design a PI interchange layout, a series of challenges and opportunities was identified:

- The interchange needs to provide effective access to the existing multimodal logistic platforms.
- The infrastructure in nodes of the network aims to facilitate the last mile urban distribution.
- The interoperability of all vehicles in the network have to be able to access the terminal.

6.2.2 Main Elements

To create the PI interchange facilities, the understanding of the main elements of the Pi terminals were analysed. Meller and colleagues (Meller et al 2012. Meller et al 2012b) analyse and discuss the optimum sizes for the PI containers (Figure 126). The Pi containers are the main elements of the PI interchange facility. Landschutzer et al. (2015) describe the implementation of the concept in the Moduluscha project.

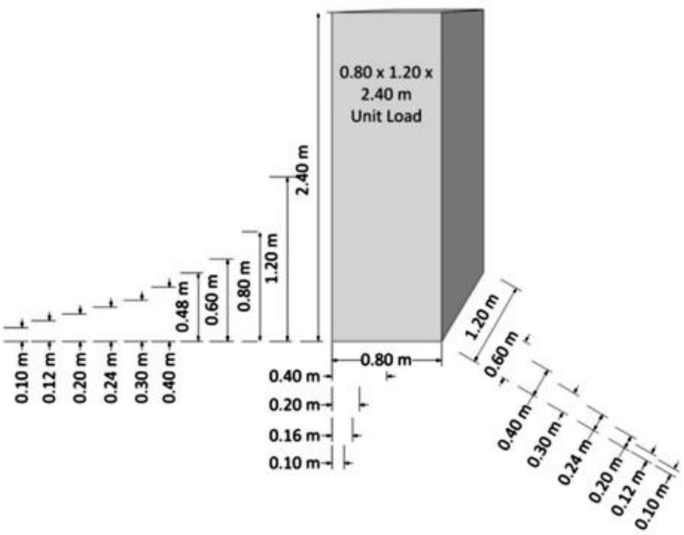


Figure 125 : Pi container sizes Landschutzer (2015)

The Pi containers are designed to be moved with PI mover equipment (adapted forklifts or by Pi conveyers, horizontal transshipment, and sorting facility (Figure 126). The 3D representation of those infrastructure were modelled for the PI interchange scenario.

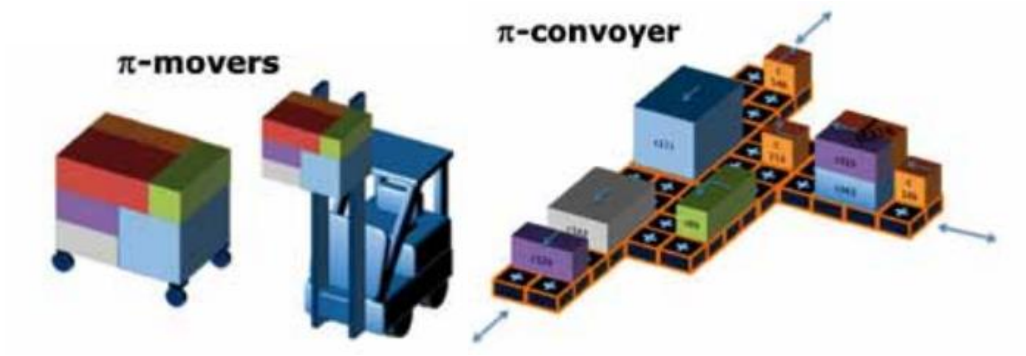


Figure 126: Pi Movers and convoyer (Meller et al 2012)

For storing the Pi container, Special Pi storage facilities are planned. For our proposed simulation, we decided to use the conventional warehouse, as the most significant changes are inside the warehouse (Figure 127)

Figure 127 : Pi store (Meller et al 2012)

As it can be seen by the picture, the PI conveyers are the key element of the PI Interchange facility doing the sorting of the Pi container.

The Pi terminal objective is to handle only the containers, avoiding the train formation to reduce the time spent in the terminal. As described by Ballot at al. (2012), the goal of the proposed layout for road-rail interchange is to create a seminal design.

Although the PI concept suggests economics and environmental gains, new terminals are required for the new logistic system promoted by the PI concept. The PI terminal concept was studied by David and Marinov to evaluate the feasibility of the infrastructure, considering the existing logistic system and transhipment equipment. The container originally proposed by the Physical Internet Initiative are not compatible with the existing lifting equipment with the new dimension of the PI container (Figure 128).

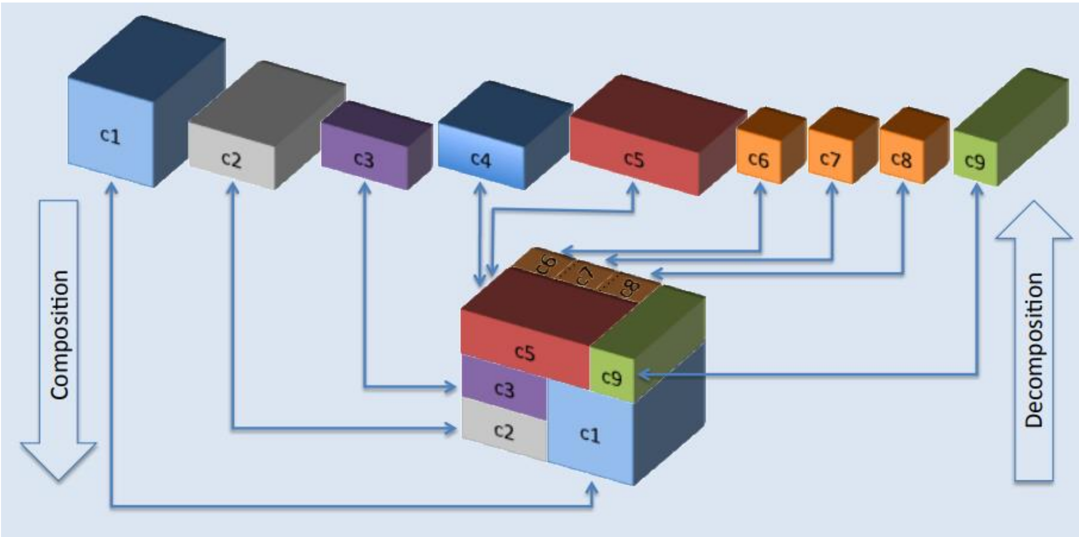


Figure 128: Pi container composition

A first functional proof-of-the-concept interchange layout was presented by Ballot et al. (2012). On the layout proposed, a train with up to 30 wagons arrives at the Pi rail gate, and the PI containers are loaded/unloaded directly from 8 Conveyor. The concept aims to be able to process a 10-wagon train in 25 minutes. The total is 12.000m2, and the layout is dimensioned for 20 trains per day with 30 wagons (Figure 129).

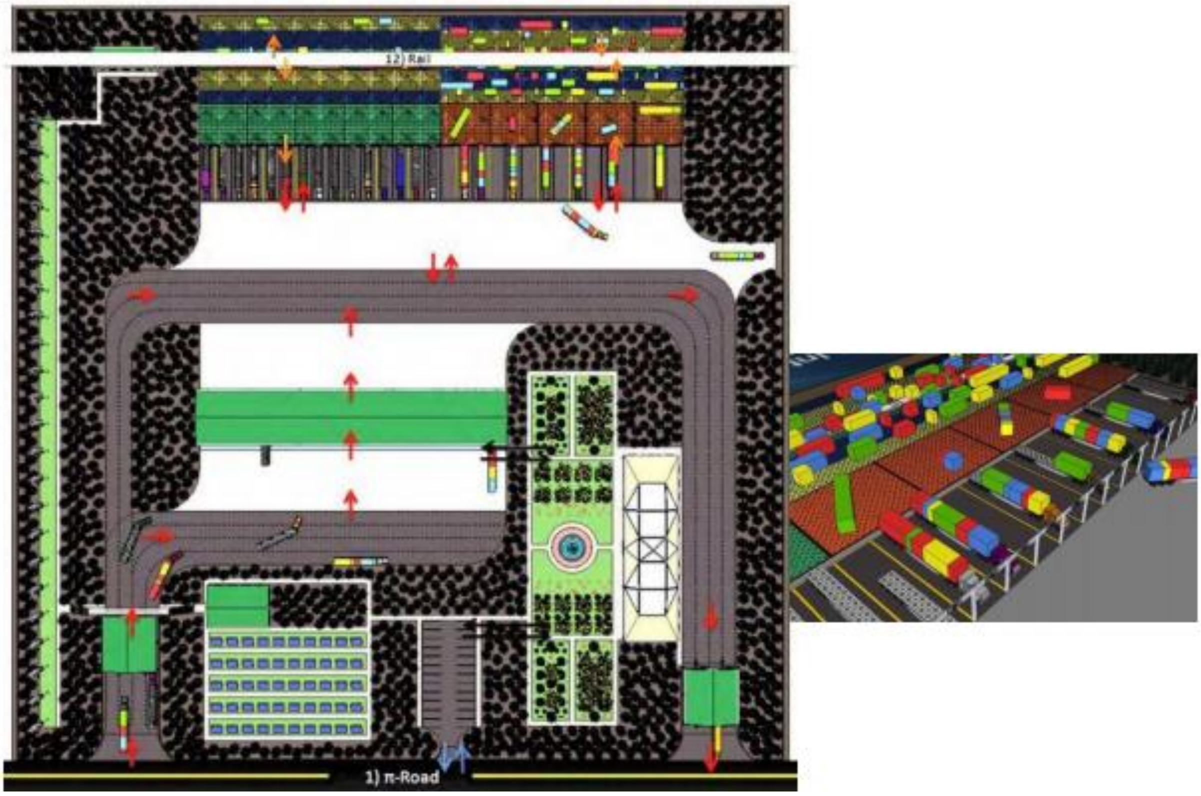


Figure 129: Pi container layout (Ballot 2012)

Considering the barrier for implementing the PI concept due to the limitation of the Pi containers in existing terminals and conventional transhipment equipment, an alternative Pi container was proposed by David (2015). The Low-C is a smart multi-compartmented container designed for multiple cargo handling. This is achieved by redesigning the height of a conventional but preserving the same lifting points. Unlike the conventional PI container, the Low-C aims to reduce the height of the container offering individual compartments and loading/unloading through independent doors (annex 1). The concept is designed to enable stack 3 Low-C units (Figure 130), effectively reconfiguring a 20’ or 40’ container, enabling to use each layer as a compartmentalized tier for palletized or other small lot cargo. Each layer can be moved independently but could also be stacked using ISO locking devices. The compartments are built around a spine running along the longitudinal axis of the layered containers.

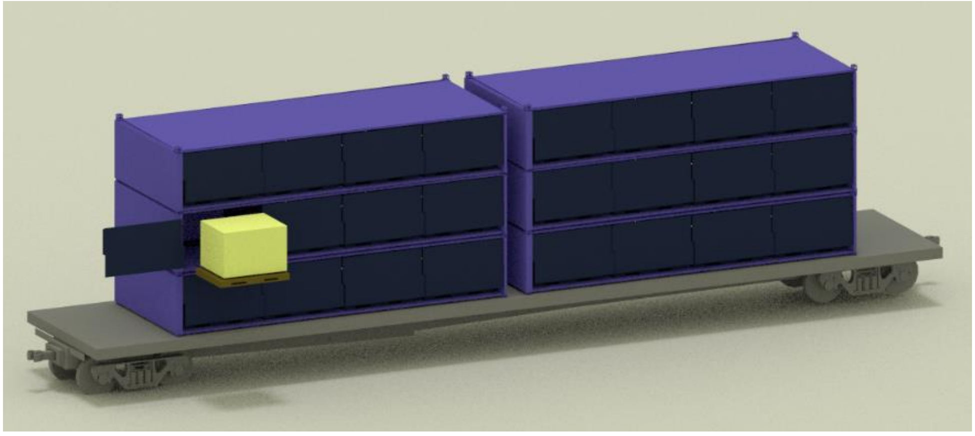


Figure 130: Low-C Pi container

David and Mortimer discussed the potential of the new PI container concept for high-value-low- density cargo (David and Mortimer 2017). For the PI interchange scenario, the tool was configured to accept the same rail and road infrastructure used in the previous scenario. The Pi container movement system and LowC infrastructure were introduced to compare the performance of the systems.

6.2.3 Infrastructure Modelling

For representing the conventional Pi container storage, simple box models were created following the dimension of the most common Pi Containers (Figure 132).

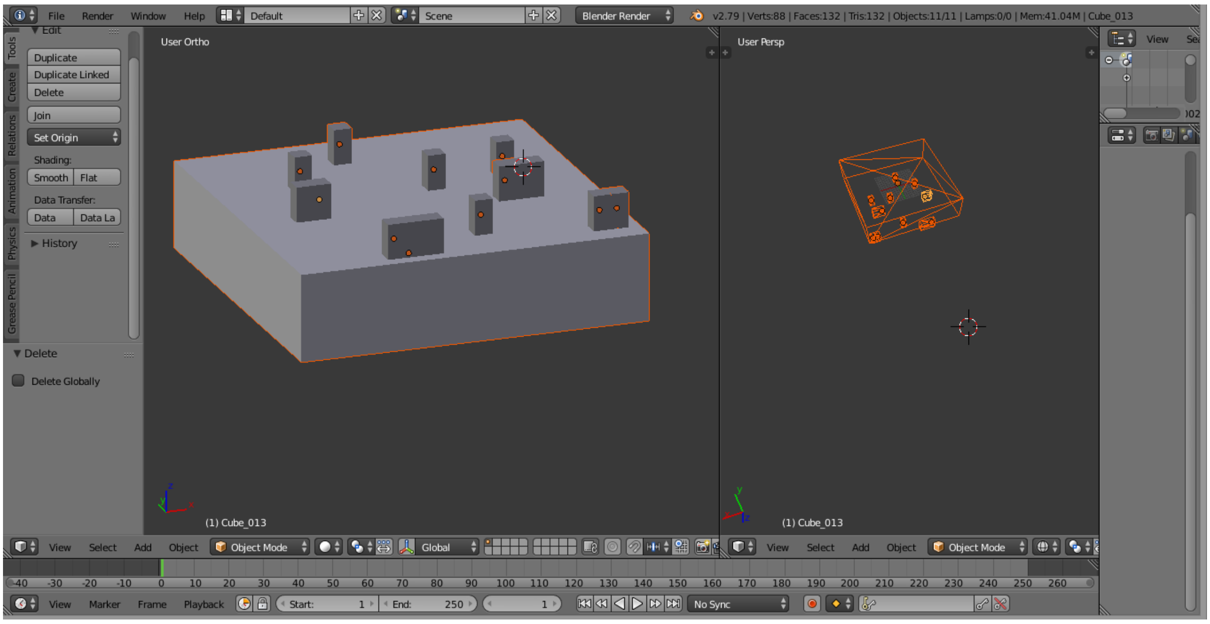


Figure 131: : Pi container storage zone

For representing the LowC container, a flat wagon with 3 LowC units stacked were used (Figure 132).

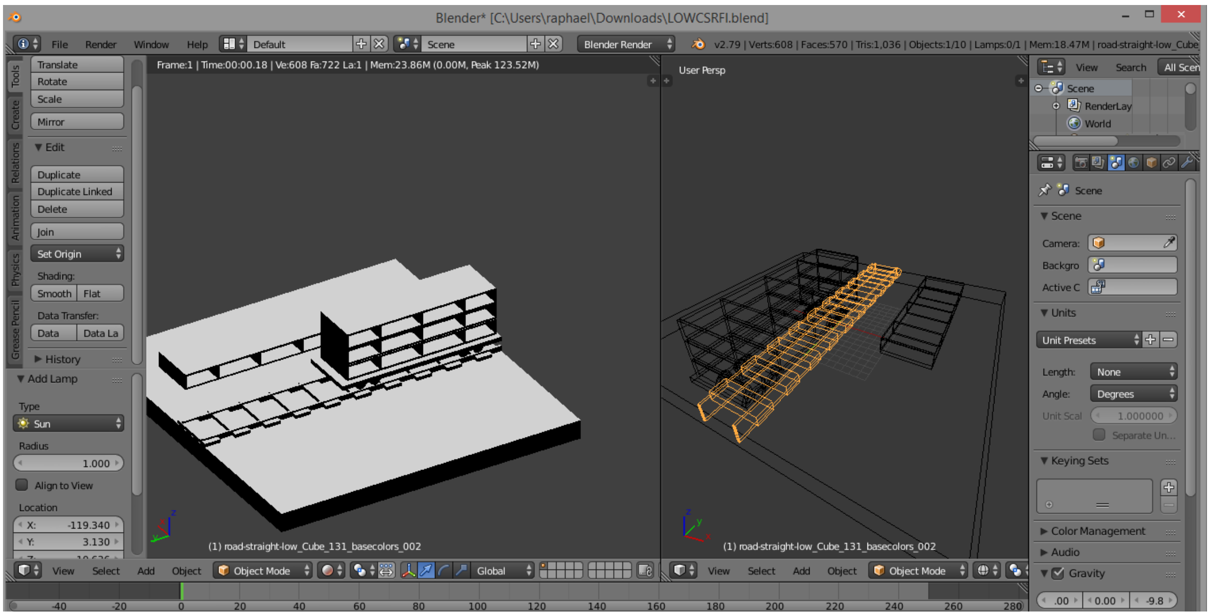


Figure 132: LowC pi container 3D model

For representing the receiving/departure gate, a simple infrastructure was modelled (Figure 133).

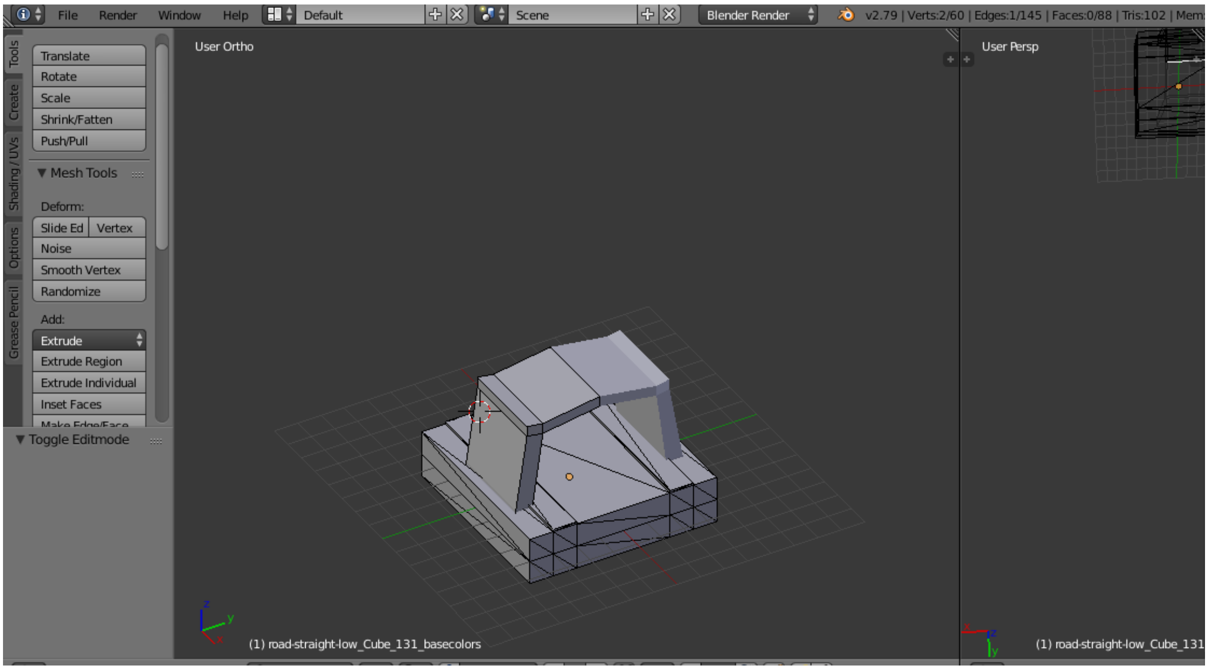


Figure 133: Receiving departure gate

Additionally, 3d models representing the containers gate transfer, the PI convoy, and a forklift model were developed to represent the missing infrastructure (Figure 134).

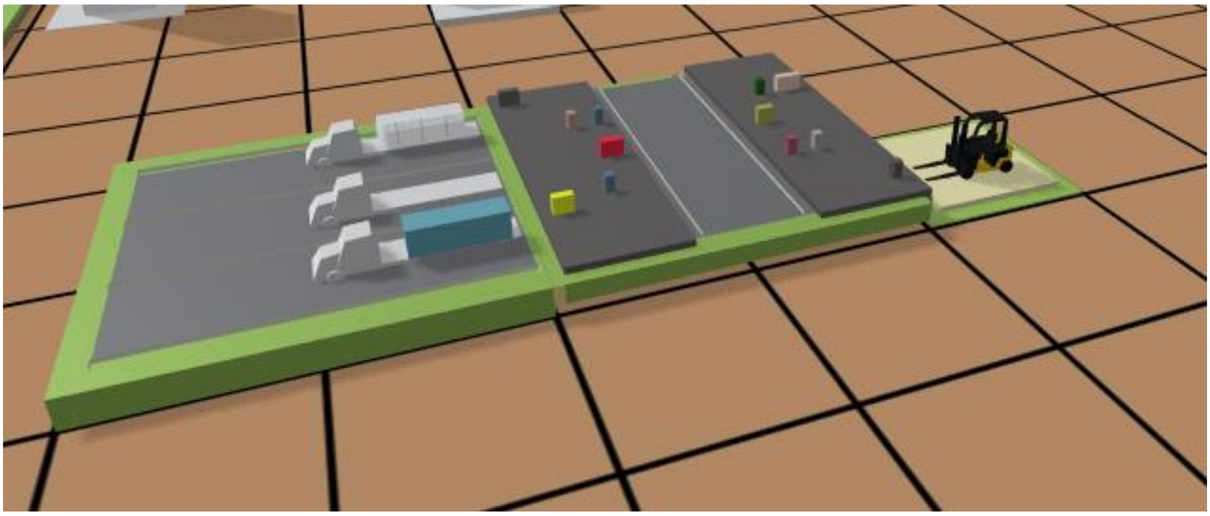


Figure 134: Pi convoy and forklift models

6.2.4 Scenario Creation

For the Pi interchange scenario, the follow KPIs were selected:

Costs

Storage capacity

Lifting capacity

Energy consumption

Containers moved

Siding required

Employment generated

Road vehicles

Trees

Pi containers moved

Due to the lack of existing literature covering LowC and PI containers / convoy the costs, the equipment was estimated based on similar equipment.

6.2.5 Stakeholders Involved

For the PI interchange scenario, the AHP implementation considers three stakeholders' priorities and two decision profiles. The public-sector profile was created with a focus on environmental and social impacts and Logistic operators' priorities profiles, considering the economic impacts.

The spreadsheet with the priorities matrix is available at : https://docs.google.com/spreadsheets/d/1iOZfrjVefazkFzw-tSg5HDIH6cb468bDak6_GJBJBwI/edit?usp=sharing

To illustrate the impacts of the hypothetical decisions, two different priorities were analysed and shown in table 24 and table 25.

Table 24: Pi scenario priorities matrix- profile 1

Priorities matrix - pairwise comparisons	Environmental/Social	Economic impact (Road/Rail)	Terminal operator efficieny
Environmental/Social	Equal importance	Strongly less important	Strongly less important
Economic impact (Road/Rail)	Strongly more important	Equal importance	Equal importance
Terminal operator efficieny	Strongly more important	Equal importance	Equal importance

This preference profile focuses on the economic impacts and terminal efficiency.

Table 25: Priority matrix profile 1

	Priority	Consistency
Environmental/Social	0.088	2.83
Economic impact (Road/Rail)	0.442	3.09
Terminal operator efficieny	0.442	3.09

The second priorities preferences (available at https://docs.google.com/spreadsheets/d/16abO9_A3NHxH5Z6RA6fZZdeO7yU9t2EdMTcNY0D2tag/edit?usp=sharing) focus on the environmental and social impact as shown in table 26 and table 27 .

Table 26 Pi scenario priorities matrix preferences- profile 2

Priorities matrix - pairwise comparisons	Environmental/Social	Economic impact (Road/Rail)	Terminal operator efficieny
Environmental/Social	Equal importance	Moderately more important	Moderately more important
Economic impact (Road/Rail)	Moderately less important	Equal importance	Moderately less important
Terminal operator efficieny	Moderately less important	Moderately more important	Equal importance

Table 27: Pi scenario priorities matrix- profile 2

	Priority	Consistency
Environmental/Social	0.499	2.26
Economic impact (Road/Rail)	0.115	3.73
Terminal operator efficieny	0.261	2.65

6.2.6 Decision Drivers and Objective Function

To help assess the suitable equipment options for Pi network, considering the stakeholders' priorities, the objective function was created. Following the method developed, the technical characteristics of the different equipment options available are analysed. For the Pi equipment, five main variables were considered: costs, employment generations, terminal movement capacity, energy consumption, and Pi container movement. Table 28 illustrates the value of the different equipment and average value.

Table 28: Lifting equipment's KPIs

Buildings\ Resources	Costs	Employment generation	Terminal move capacity	Energy consumption (day)	Pi cont movement
ReachStacker	£850,000.00	2	120	80	10
Forklift	£450,000.00	2	60	40	120
Pi container mover	£6,000,000.00	4	3600	300	4500
Avarege	£2,424,581.61	3	641	181	1383

The efficiency value and constrain value for the two profiles are shown in Table 29.

Table 29: Efficiency and constrain values - Pi scenario

Profile 1	Reachstacker	Forklift	Pi cont mover
Efficiency	18	16	418
Constrain	16	8	109
Profile 2	Reachstacker	Forklift	Pi cont mover
Efficiency	60	49	381
Constrain	4	2	28

6.2.7 GA Application

Next, the efficiency and constrain values will be used to represent the potential solutions in a string (binary code) as the previous case study. The Pi interchange is represented here in a 25-gene string, where 10 genes are for a Reach stacker and one forklift and five genes for Pi container movers as shown in table 30.

Table 30: Gene representation: profile 1:

Reachstacker										
Gene	1	2	3	4	5	6	7	8	9	10
Efficiency	18	18	18	18	18	18	18	18	18	18
Constrain	16	16	16	16	16	16	16	16	16	16
Forklift										
Gene	11	12	13	14	15	16	17	18	19	20
Efficiency	16	16	16	16	16	16	16	16	16	16
Constrain	8	8	8	8	8	8	8	8	8	8
Pi cont mover										
Gene	21	22	23	24	25					
Efficiency	418	418	418	418	418					
Constrain	109	109	109	109	109					

For GA execution, 100 individuals was the initial population and 130 for maximum constrain. Three generations without changes or a maximum of 200 generations was assigned as the stop criteria defined. A probability of 50% crossover and 5% for mutation was assigned as shown in Figure 135.

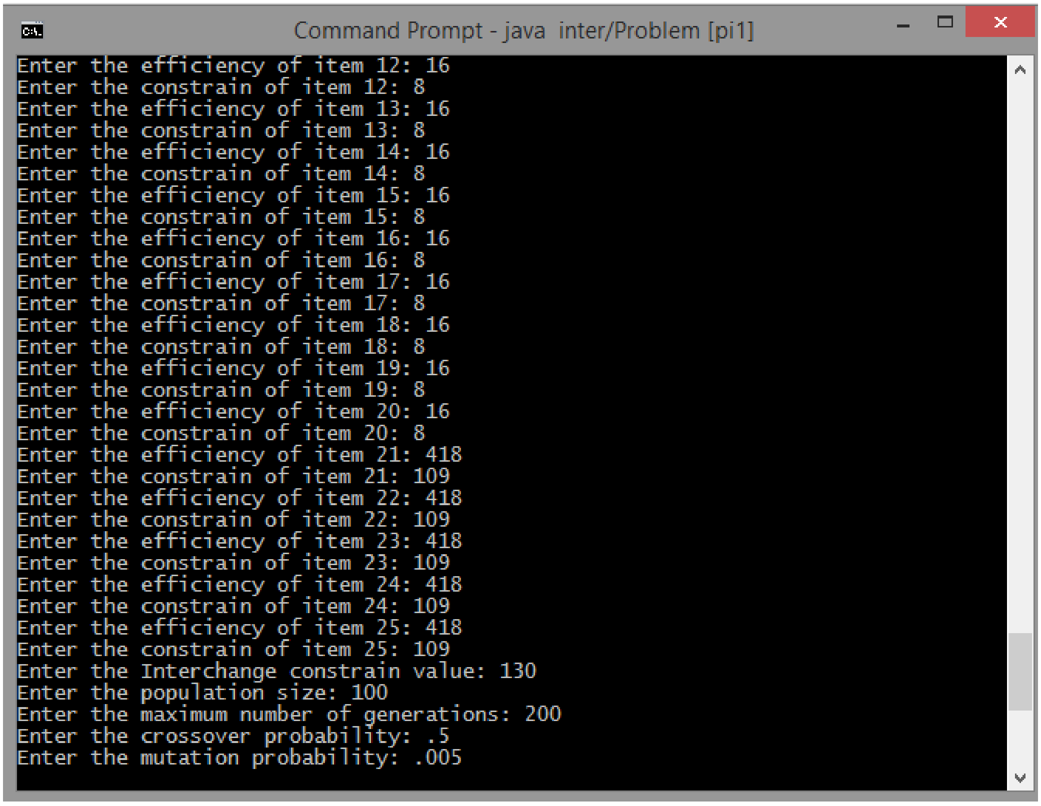


Figure 135: GA module initialization: profile 1

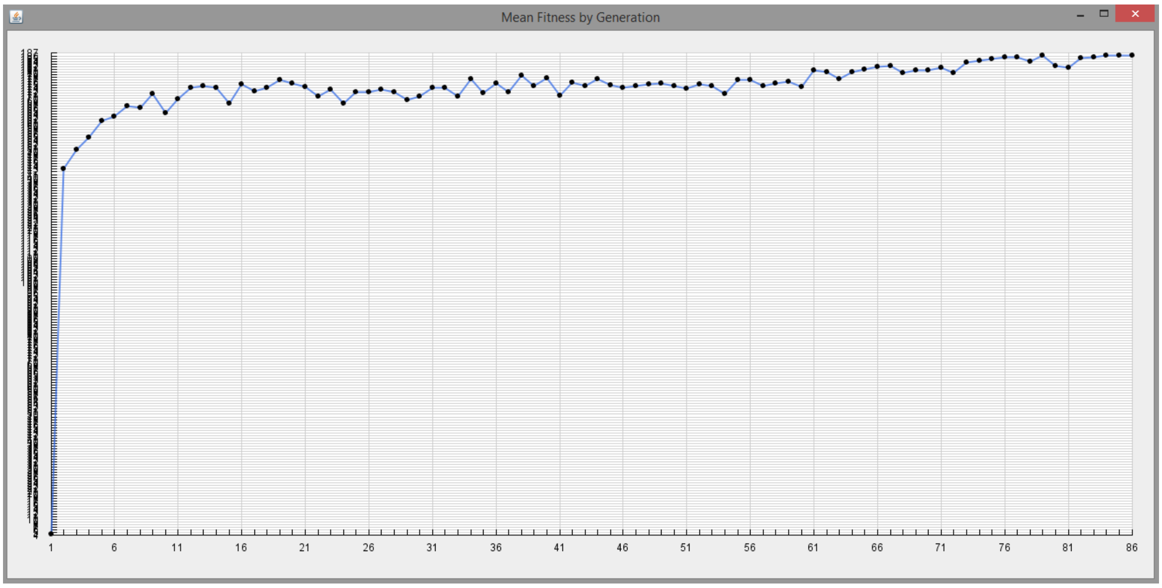


Figure 136: GA mean evolution: profile 1

Optimal list of items to include in Interchange:

1 2 3 9 10 11 12 13 15 16 18

The same population mutation and stop criteria were used for profile 2, and the efficiency and constrains values calculated were assigned in the chromosomes as shown in table 31.

Table 31: Gene representation: profile 2

Reachstacker										
Gene	1	2	3	4	5	6	7	8	9	10
Efficiency	60	60	60	60	60	60	60	60	60	60
Constrain	4	4	4	4	4	4	4	4	4	4
Forklift										
Gene	11	12	13	14	15	16	17	18	19	20
Efficiency	49	49	49	49	49	49	49	49	49	49
Constrain	2	2	2	2	2	2	2	2	2	2
Pi cont mover										
Gene	21	22	23	24	25					
Efficiency	381	381	381	381	381					
Constrain	28	28	28	28	28					

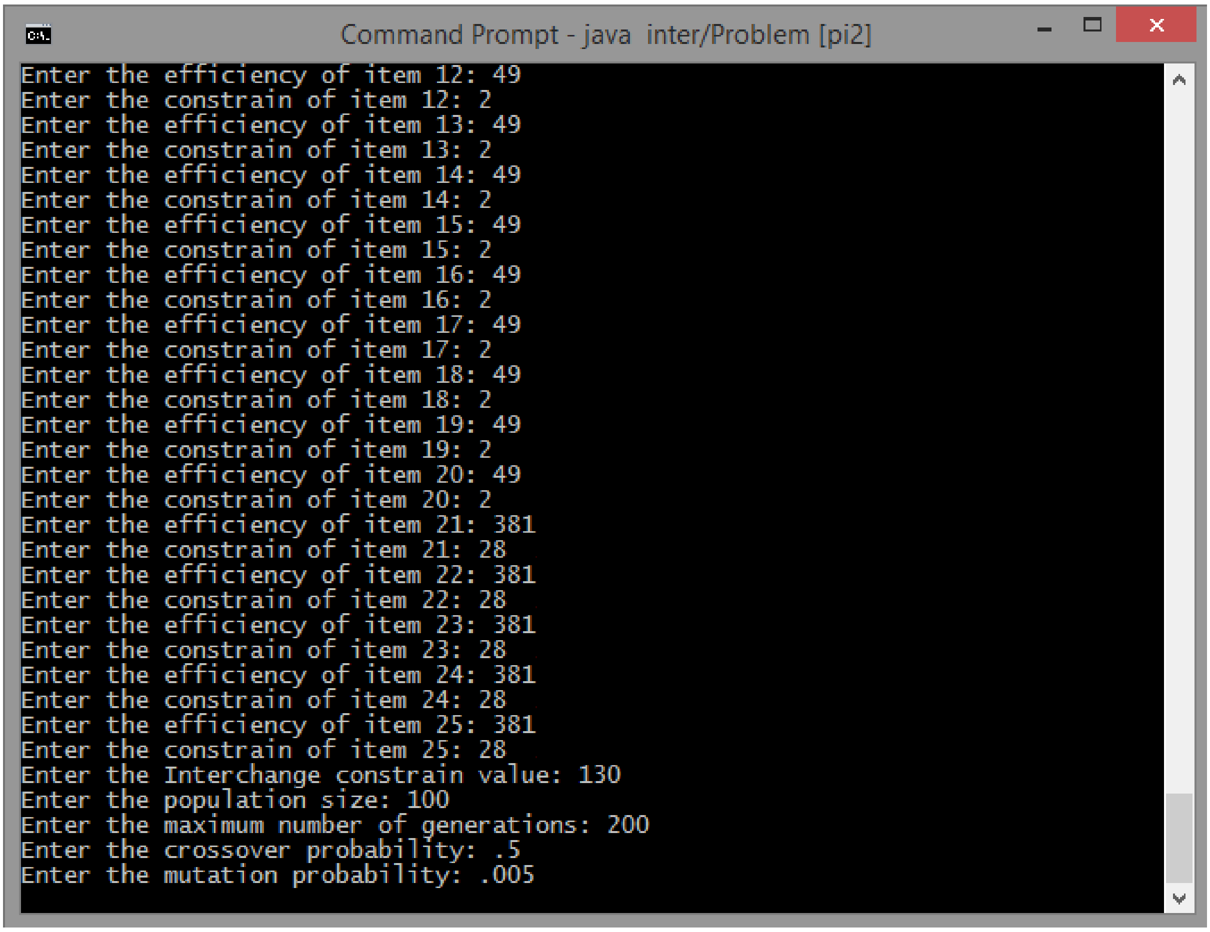


Figure 137: GA module initialization: profile 2

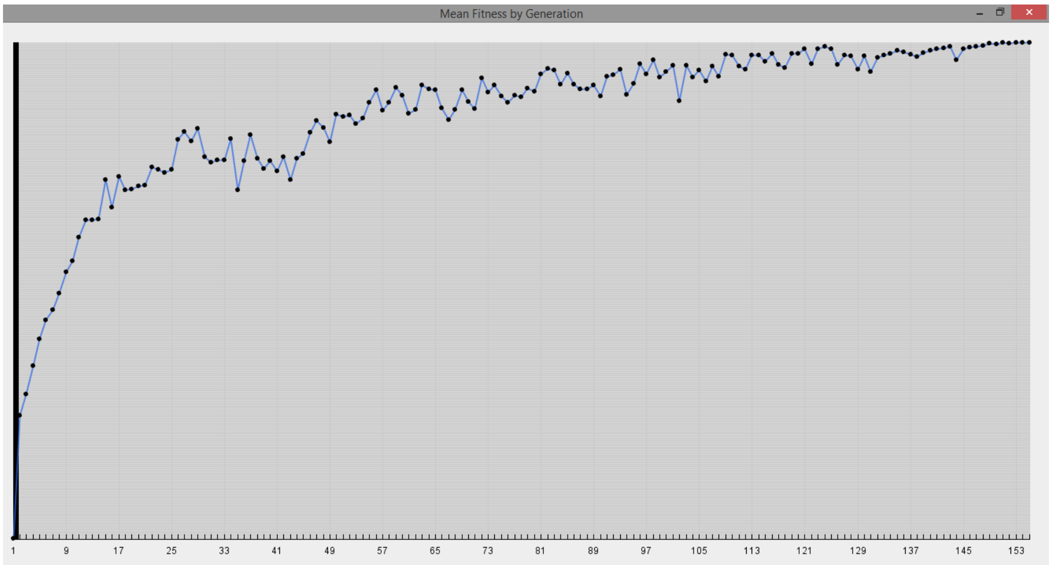


Figure 138: GA mean evolution: profile 2

Optimal list of items to include in Interchange:

1 2 4 5 7 8 9 11 13 14 15 16 17 18 19 20 21 24 25

6.2.8 Transport Demand

For this case study scenario, the software accepts traffic generator feeder, traffic generator low demand, and traffic generator road. The calculation for the traffic demand generators for this scenario are the same as previously presented (Figure 139). illustrates the three traffic generators for this scenario.

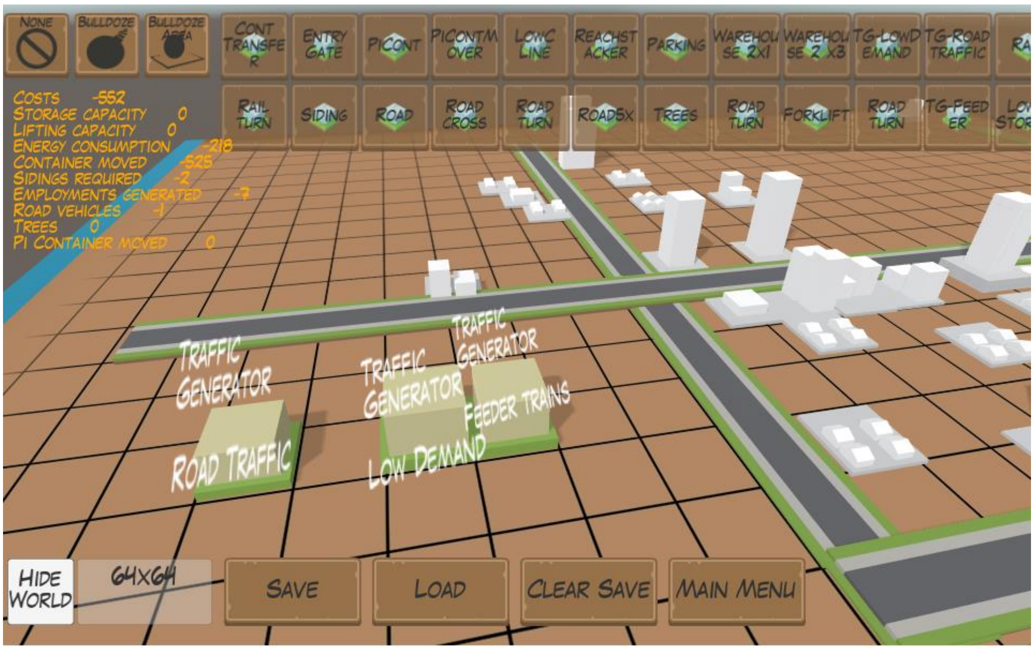


Figure 139: traffic generator deployment

6.2.9 Evaluation

The online tool for testing the PI scenario is available in the website srfi.smart2city.com. The users could dynamically visualize the impact of Pi infrastructure deployed in the Pi interchange considering the selected KPIs.

Table 32: Profiles comparison

	Profile 1	Profile 2
Reachstacker	5	7
Forklift	6	8
Pi container mover	0	3
Total efficinecy	186	1955
Total constrain	128	128
Total cost	£ 6,950,000.00	£ 27,550,000.00
Employment generation	22	42
Terminal movement capacity	600	840
Energy consumption	360	11280
Pi cont movements	770	14530

As it can be seen the profile 2 presets significantly higher costs, however are able to handle 20 times more Pi containers. The investments decision depending on the transport demand and the assigned priorities.

6.3 Case Study 3 Interchange for Fast Fulfilment Service

6.3.1 Introduction

The traditional rail freight focuses on the low value bulk (commodities) and retained a limited capability in time-sensitive logistics; therefore, in several countries, the rail freight transport has been outperformed by the road transport. The Fast Fulfilment Freight (F3) project aims to improve the competitiveness and capability of rail freight in the intermodal market, enabling shorter and faster trains.

This FFF Interchange is a short terminal concept, aiming to provide logistic services (transhipment and warehouse) for shorter trains (a 10 wagons train) in up to 60 minutes. By the technical characteristics of the F3 project, existing rail infrastructure (e.g., marshalling yards and depots) can be potentially adapted for FFF interchange.

The layout proposed includes fast transshipment and non-intensive area usage, enabling efficient and cost-effective service to shippers, backed up by security and good disruption response. Therefore, the existing available underutilised rail infrastructure was analysed to identify the appropriated location for the FFF interchange.

6.3.2 Main elements

For planning the FFF interchange concept, it is crucial to identify the appropriate infrastructure and requirements for the expected container and pallet traffic. Minimizing the time spent in the terminal by the trucks also significantly contributes to improving the efficiency of the intermodal operation.

FFF interchanges are designed also to operate with an intensive short train linked to fast terminal operations (loading and off-loading of containers and pallets). In order to compete with the road sector handling cargo faster and to meet the FFF operations requirements, the FFF interchanges require a number of elements for fast operations:

- Rail served warehousing
- Connection to the rail network with the railway infrastructure able to accommodate three` trains up to 250m long per day
- Highway connection with arrival and departure roads adjacent to the railway
- Receiving gate and Parking area to accommodate the incoming flow.
- Efficient and low-cost transhipment equipment

As the Rolling stock for the FFF operation is designed to be used for the majority of a 24-hour day, the time spent in the interchange is critical for the success of the operation, and as a result, the lifting equipment needs to consider redundancy (contingency and maintenance).

6.3.3 Infrastructure Modelling

The 3D models developed for the previous case study were utilised again in the FFF scenario; therefore, no additional infrastructure modelling was required for this case study.

6.3.4 Scenario Creation

This case study illustrates the use of the software package to implement a new logistic model in an existing terminal. Therefore, aerial image was used to represent the existing rail infrastructure of the Wigan Springs Branch. The Wigan Springs

Branch was a previous locomotive depot located immediately adjacent to the West Coast Main Line. A 3D models of the city were created to represent the interchange surroundings (Figure 140).

The evaluation of existing rail infrastructure was analysed in the FFF project, and the software package was used to identify the suitable lifting equipment for the Wigan Spring FFF Interchange. Differently than the first case study, forklift equipment was considered for the Wigan interchange.

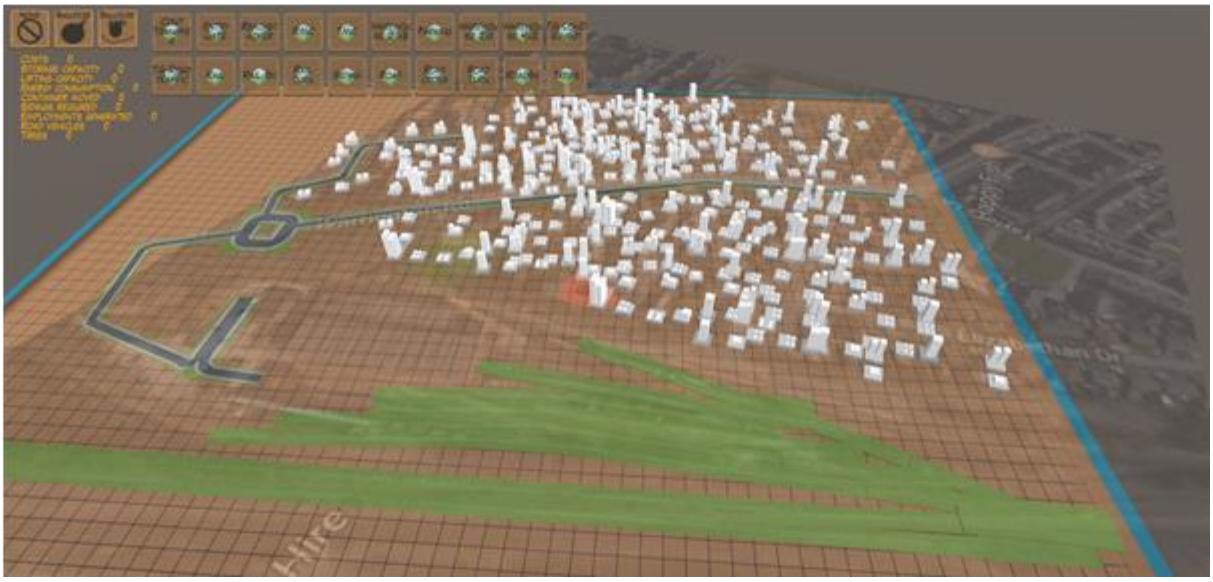


Figure 140: Wigan Springs Branch 3D model representation

6.3.5 Stakeholders Involved

To illustrate the use of the method considering a high number of decision profiles, 11 hypothetical decision profiles were in this case study. The first profile (default) represents the default value in the AHP module. The default value considers all the equally important criteria (Table 33).

Table 33: Eleven decision profiles preferences

	Environmental x Economic Impact	Environmental x Terminal efficiency	Economic Impact xTerminal efficiency
Default	Equal importance	Equal importance	Equal importance
Profile 1	Moderately less important	Moderately less important	Moderately less important
Profile 2	Moderately less important	Moderately less important	Moderately more important
Profile 3	Moderately less important	Moderately more important	Moderately more important
Profile 4	Moderately more important	Moderately more important	Moderately more important
Profile 5	Moderately more important	Moderately less important	Moderately less important
Profile 6	Moderately less important	Equal importance	Equal importance
Profile 7	Equal importance	Moderately more important	Moderately less important
Profile 8	Moderately more important	Moderately less important	Equal importance
Profile 9	Very strongly more important	Very strongly less important	Equal importance
Profile 10	Very strongly less important	Equal importance	Very strongly more important

As it can be seen in table 34, when the all decision drivers have the same value for the preference, the relative importance weighed by the AHP is equal.

Table 34: Profiles priorities

	Environmental/Social	Economic impact	Terminal operator efficieny
Default	0.333	0.333	0.333
Profile 1	0.14	0.286	0.574
Profile 2	0.14	0.574	0.286
Profile 3	0.286	0.574	0.286
Profile 4	0.574	0.286	0.14
Profile 5	0.286	0.14	0.574
Profile 6	0.225	0.454	0.321
Profile 7	0.44	0.235	0.325
Profile 8	0.325	0.235	0.44
Profile 9	0.322	0.198	0.479
Profile 10	0.136	0.685	0.179

6.3.6 Decision Drivers

In order to identify the suitable transhipment equipment for the FFF interchange, the objective functions were created following the 11 profile priorities. Four main variables were considered for the case study: costs, employment generations, movement capacity, and energy consumption. Table 35 illustrates the value of the different equipment and average value.

Table 35: Equipment and average values

Buildings\ Resources	Costs	Employment generation	Terminal move capacity	Energy consumption (day)
ReachStacker	£850,000.00	2	120	80
Forklift	£450,000.00	2	60	20
Tyre mounted crane	£1,700,000.00	2	200	40
Avarege	£1,000,000.00	2	127	47

The efficiency value and constrain value of each element can be determined by the formulas:

$$Eff_V = \sum_{i}^{N}(Pri_v\,(i).(\frac{V_{cost}}{V_{avar}}))$$

Where

Effv = Efficiency value for the objective function considering the user priority

Priv = Priority weighed by the AHP module

Vcost = Value assigned for each KPI (e.g. employment generation)

Vavar = Average value of the KPI

$$Const_V = \sum_{i}^{N}(Pri_v\,(i).(\frac{C_{cost}}{C_{avar}}))$$

Constrv = Constrain value for subject the objective function considering the user priority

Priv = Priority weighed by the AHP module

Vcost = Value assigned for KPIs that constrain the optimization (e.g. costs)

Vavar = Average value of the KPI

Table 36: Profiles efficiency and constrain values - FFF scenario

	Equipment	Effciency	Constrain		Effciency	Constrain		Effciency	Constrain
Default	Reachstacker	19	28	Forklift	9	15	TMC	21	57
Profile 1	Reachstacker	13	24	Forklift	8	13	TMC	33	49
Profile 2	Reachstacker	13	49	Forklift	15	26	TMC	18	98
Profile 3	Reachstacker	17	49	Forklift	15	26	TMC	18	98
Profile 4	Reachstacker	25	24	Forklift	8	13	TMC	11	49
Profile 5	Reachstacker	17	12	Forklift	5	6	TMC	33	24
Profile 6	Reachstacker	16	39	Forklift	12	20	TMC	20	77
Profile 7	Reachstacker	21	20	Forklift	7	11	TMC	20	40
Profile 8	Reachstacker	18	20	Forklift	7	11	TMC	20	40
Profile 9	Reachstacker	18	17	Forklift	6	9	TMC	28	34
Profile 10	Reachstacker	13	58	Forklift	17	31	TMC	13	116

As it can be seen in the table 30, due to the high importance given to the economic impact in some profiles (profiles 2, 3,6 and 10), the elements of higher costs present significantly high constrain.

6.3.7 GA Application

The implementation of the GA module for the FFF scenario represented the transhipment equipment in a 15-gene string (5 genes for each equipment). The initial population used was 2000 and a maximum constrain of 100. Three generations without changes or maximum of 100 generations was assigned as the stop criteria defined. A probability of 50% crossover and 5% for mutation was assigned.

After the execution of the GA module with the respective efficiency and constrains values for the 11 decesion profiles, the software application suggests the following configuration for the decision profiles (table 37):

Table 37: Recommended equipment GA module implementation :FFF scenario

	Reachstacker	Forklift	TMC
Default	3	1	
Profile 1			2
Profile 2		3	
Profile 3		3	
Profile 4	4		
Profile 5	4		2
Profile 6		5	
Profile 7	5		
Profile 8	5		
Profile 9	5	1	
Profile 10		3	
	50.98%	31.37%	7.84%

As it can be seen, the reach stacker was the equipment with higher selection rate followed by the forklift. The tyre mounted crane was only selected for profiles 1 and 5, suggesting the efficiency is the key driver for the TMC equipment.

6.3.8 Operation Pattern

The potential of vehicle innovation for high value freight has been evaluated by David and Mortimer (2015) and Mortimer and David (2017). The research suggests that, for the inter-urban freight, quick logistic service with shorter formations (< 10 wagons) can improve the competitiveness of the rail sector. To simulate the FFF demand defined in the interchange designer application as Low Demand, freight generator is composed by 8 wagons (table 38). The inputs/outputs calculation for the Low Demand freight generator and road generator are shown in table. The user interested in modifying the values can adjust on the case study spreadsheet (https://docs.google.com/spreadsheets/d/1BHVtCsJxk14BoUm6lTy7iM1Xvu42WrTVA42ivpcU0Z0/edit?usp=sharing)

Table 38: Low demand and road generator values spreadsheet

Rail cost operation	Low Demand		Road Generator	
	Qtd	Total		
Vehicle costs			Vehicle	Price
Class 67	1	£3,500,000.00	Tractor	£109,800.00
Wagons	8	£800,000.00	Semi-trailer	22500
Cargo weight per vehicle		£160.00	Cargo weight per vehicle	25
Total weight		£320.00	Total weight	40
Avarege miles annum	75000		Avarege miles annum	100000
Avarege days worked annum			Avarege days worked annum	230
Hours/day			Hours/day	18
Liters 100km			Liters 100km	31.39
Time related costs				
Employees required	3		Employees required	2
Cost/employee		£136,476.00	Cost/employee	40761
Other emplyeecosts		£66,267.00	Other emplyeecosts	
Total cost driver		£202,743.00	Total cost driver	81522
Cost hour		£34.66	Cost hour	£19.69
Fixedcosts				
Depreciation		£140,800.00	Depreciation	19158
Vehicle insurance		£86,000.00	Vehicle insurance	3433
Interest capital (6%)		£258,000.00	Interest capital (6%)	4392
Fixed cost/day		£1,491.69	Fixed cost/day	£219.71
Mileage relatedpence/mile				
Fuel			Fuel	48.39
Maintanence		£312.90	Maintanence	15.34
Track access charge loco			Tyres	3.12
Total cost/year		£910,695.00	Total cost/year	£198,906.00
Cont transported year	2,600		Cont transported year (2 cont/day	460
Cost/cont		£350.27	Cost/cont	£432.40

6.3.9 Evaluation

Considering the most suitable lifting equipment for the F3, interchange suggested by the genetic algorithm, considering the 11 profile preferences, an evaluation of the layout was created using the interchange designer tool. Figure 141 illustrates a design for the Wigan interchange (profile 5).

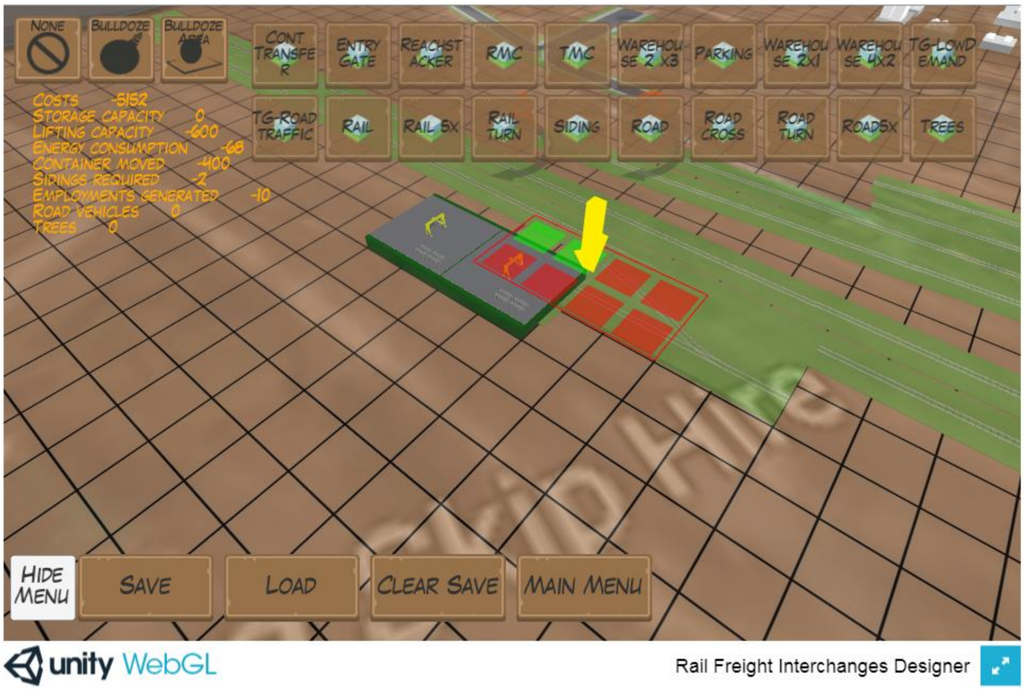


Figure 141: Profile 5 layout - TMC deployment

As it can be seen after deploying the two TMC and the two sidings required for the transport demand, the total costs calculated by the application was around 5 million pounds and able to handle up to 600 containers a day (Figure 142) .

Figure 142: Profile 5 layout - 5 TMC deployed

After deploying the four suggested reach stackers, the lifting capacity increases to 1080 containers a day with total costs of around 8.5 million.

Considering the lifting equipment suggested by the GA module, profiles 2, 3, and 10 have significantly lower costs, while profile 5 has the higher costs as it can be seen in Figure 143.

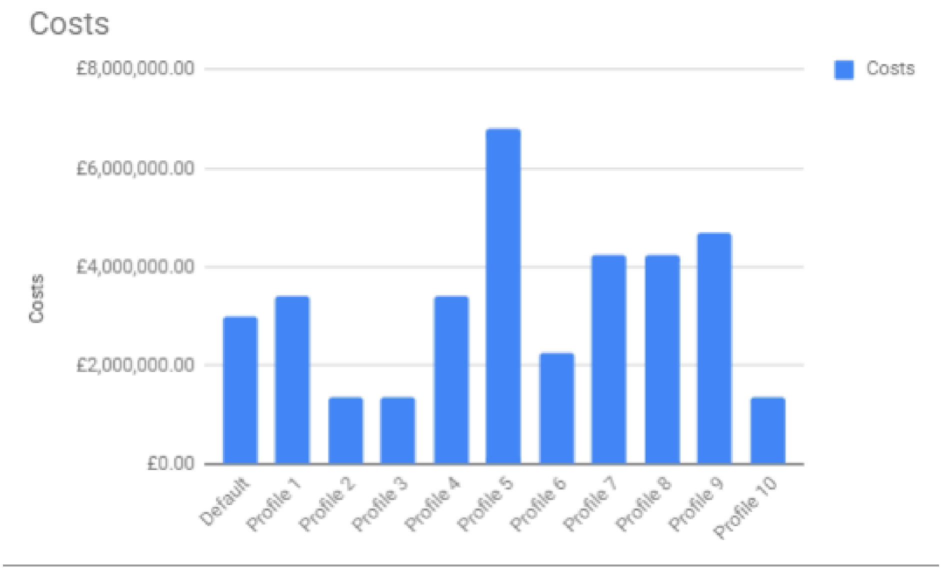


Figure 143: FFF interchanges costs

The result is directly resulting in the high number of equipment suggested by the algorithm. At the same time, a higher number of equipment impacts employment generation. As a result, profiles 5 and 9 have higher employment rate (Figure 144).

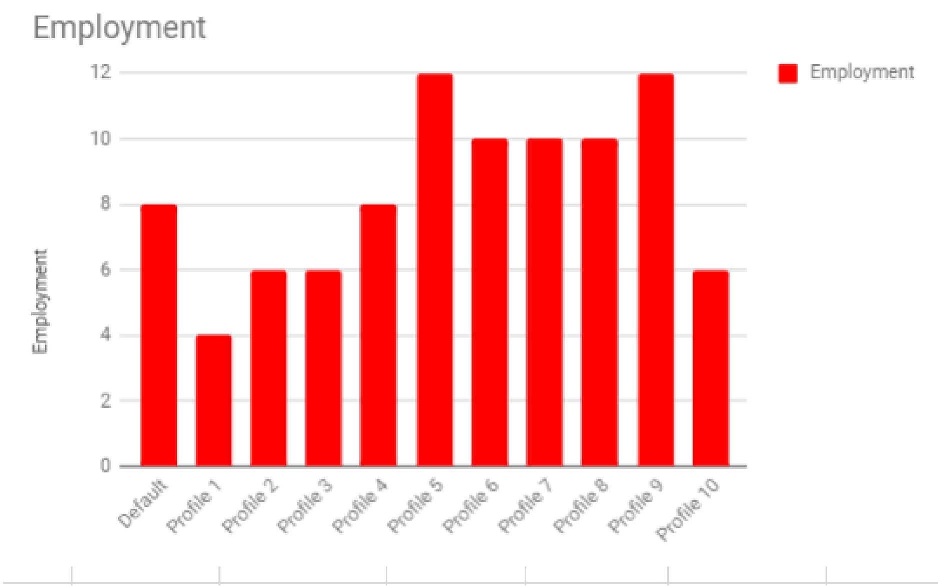


Figure 144: FFF interchanges employments generation

Considering the lifting capacity again, profile 5 presents higher values as it can be seen in Figure 145.

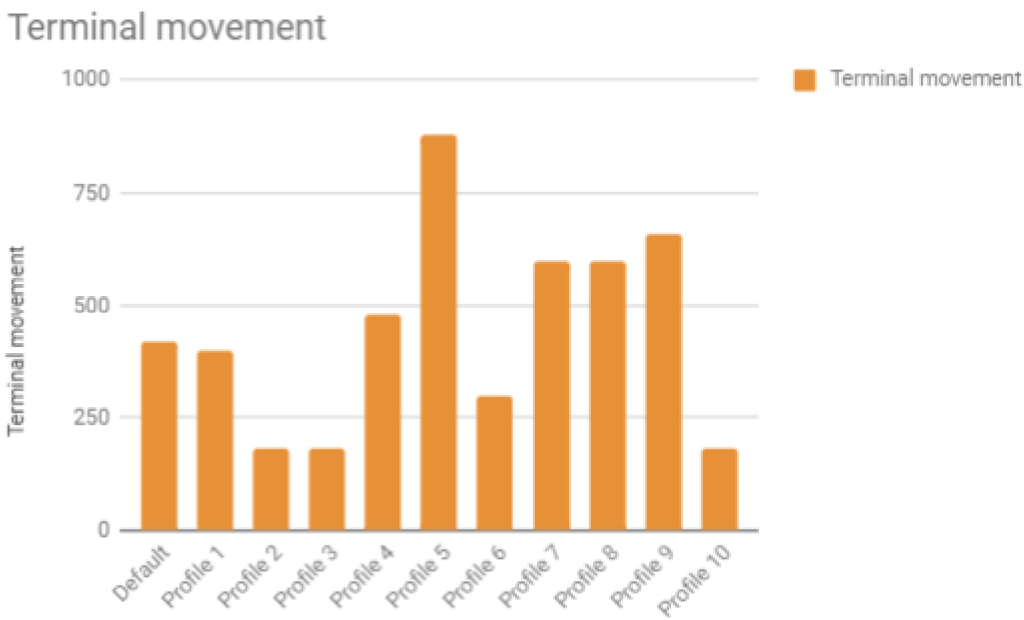


Figure 145: FFF interchanges terminal movement's capacity

For the energy consumption, the equipment selected for profile 9 presents higher consumption, while profiles 2 and 3 present the lowers (Figure 146) .

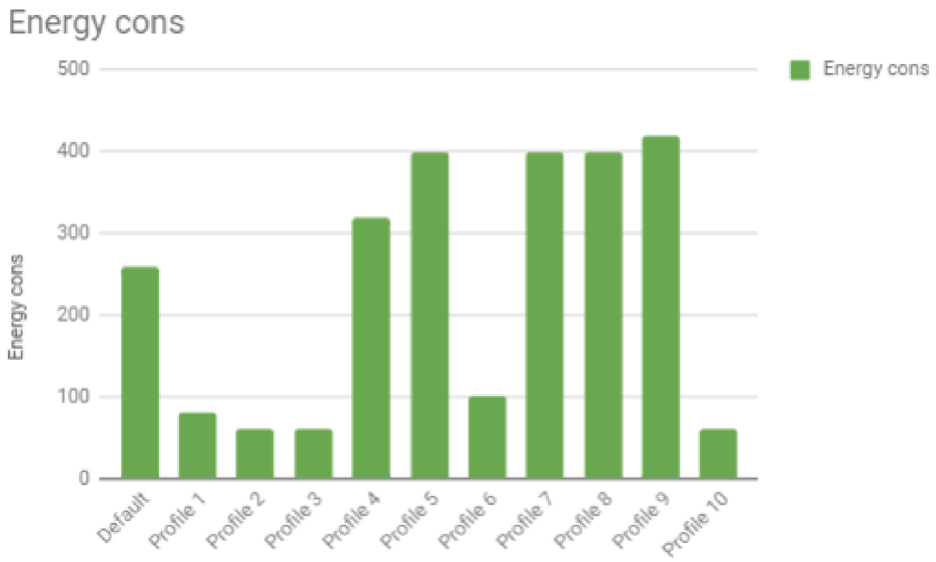


Figure 146 : FFF interchanges energy consumption

6.4 Chapters Conclusions

The aim of this chapter was to examine the practical application of the software packages developed in this research work. The integration of Analytical Hierarchy Process with Genetic Algorithm for interchange design intended to help improve predictions of the impact of different infrastructure elements.

Although the Genetic Algorithm traditionally might not find the most optimal solution to the defined problem in all cases the stepwise process described in this work allows to identify the interchange design results considering different stakeholders helping to converge to identify the most suitable solution.

The case studies presented here analyse the interchange planning process, considering multiple decision drivers. Overall, this chapter strengthens the potential usefulness of software packages developed for both infrastructure planners and policy-makers.

Chapter 7: Conclusions and Future Work

Chapter Introduction

This chapter presents an overview of this thesis, highlighting the importance of the research project. The primary aim of this section is to examine the research work and the findings, critically evaluating the effectiveness of the proposed methodology for developing a software package for designing rail freight interchanges. The secondary objective is to discuss areas for further research.

7.1 Thesis Conclusions

The intermodal transport research has grown into a dynamic research field in recent years. Several new intermodal research lines have emerged recently. To contribute to this growing area of research, this research work presents a comprehensive overview of the rail freight interchange and software package used to design it. In particular, this thesis examined six research questions:

1- How the changes in the Global market for freight impact and are impacted by decisions made by different stakeholders, and what is the role of the terminals and interchanges?

The work presented in this dissertation around the first research question was presented in chapters 1, 2 and 5. The analysis contributes to the understanding the challenges faced by the rail sector within the global market for freight and the role of the interchanges for supporting the modal shift. The analysis of the market helped to explain the need for the emergent interchange concept and the importance of considering multiple stakeholders in the decision making-process

2- How do the rail operation patterns impact the rail freight interchange?

Research question 2 is successfully addressed in Chapter 2. The chapter is focussed on rail operation research and has investigated the main operational patterns and equipment for rail terminal operations. The operational patterns and transport demand directly influence the needs on the terminals. In order to plan terminal operations, one needs to understand the dynamic of the equipment and demand.

3- What are the principal rail modelling simulation tools and what is missing to design RFI to meet the needs of multiple stakeholders?

Simulation is a wonderful tool for infrastructure planning. It allowed to represent systems of different complex natures efficiently. In particular, simulation may allow test scenarios that enable representing the behaviour of different elements in a completely controlled environment. However, the multi-stakeholder decisions have been poorly used in simulation tools. The complexity of the existing simulation tools was identified as a potential barrier for engaging multiple stakeholders in the design process. The lack of experience and knowledge of some stakeholders suggested there is a need for more user-friendly tools.

In regards to heuristics and metaheuristics in simulation packages, artificial intelligence techniques and heuristics have been used in multiple packages in different ways. The review of the existing tools identifies a potential for the use of Genetic Algorithms for simulation tools for multi-objective optimization.

Due to all the above, the present research work has focused on the integration of these methods and techniques, for which the objective is to create a satisfactory multi-stakeholder program for an interchange designed in a way that users, without background in simulation and train operation, can introduce modifications to the interchange layout and evaluate the outcomes of their decision.

4- What is the most suitable methodology for developing software applications that incorporate the missing elements?

In order to answer the fourth research question, Chapter 4 describes and analyses methods for the decision-making process. The flexibility of the Technology Road mapping method was crucial for the decision. The method was also used in the chapter published in Handbook of Research on Strategic Innovation Management for Improved Competitive Advantage (David 2018).

5- How to use the methods and elements together to create simulation tools for designing rail freight interchange?

Chapter 5 proposes a conceptual theoretical framework for developing a software package for interchange to answer the fifth research question. The chapter presented in detail the Analytical Hierarchy Process and Genetic Algorithm method to explain how those methods can be combined to develop simulation tools to meet multiple stakeholders' requirements. As an example of the theoretical framework, simulation tools are developed using Java, C# and Unity.

6- How to use the tools developed to create scenarios and evaluate rail freight interchanges?

Finally, this sixth research question is answered through case-study examples in order to provide further understanding of the software packages developed.

7.2 Main Contributions

The multiple stakeholder decision making process with interchange designing tools has significant potential for improving the competitiveness of the rail sector. For that reason, it is of great interest to develop a framework for simulation tools and offer new methodologies to address the problem of multiple stakeholders' decision-making process that can be applicable in real environments in multiple sectors.

Although the original proposal of the thesis was the development of an integrated package with the three tools the research suggested that the partially integrated package allow the user exploring the tools according to their specific needs. Users interested in understanding the benefits of new rail freight interchange considering stakeholders not directly involved in the operation (e.g government) can use only the decision modelling tool, or the modelling tool combined with the genetic algorithm to generate a number of possible solutions. In other hand side for users more interested in the rail interchange visualisation can use only the interchange designer tool.

Many of the findings of this thesis are associated with software development and decision-making process related to innovation.

The thesis successfully explores the characteristics of rail/ non-rail elements to understand the interrelation between the elements on rail freight operations. The scientific contributions of the research are as follows:

- Understanding the nature of multi-stakeholder decisions, analysing the impact of stakeholders' decisions.
- Propose artificial intelligence tool based on genetic algorithm to support decisions for rail freight interchanges based on multi-stakeholders' priorities.
- Multi-scenario generation tool to model different scenarios to enable dynamic evaluation of KPIs, considering different decision drivers.
- Virtual environment navigation tool based on 3D scenarios and virtual reality to enable the decision maker to visualise the new terminal configuration.

7.3 Recommendations for Further Work

From the research work developed, the following aspects are suggested as possible future developments:

- First, in the interest of introducing an agent-based simulation heuristic in the software package to simulate the behaviour of the vehicles and personnel involved in terminal operations, a postdoc proposal was submitted to explore the multi-agent behaviour for planning safe transport infrastructure.
- Second, in regards to the software integration future work might explore the packages integration into a unique software package using a clear and robust methodological process.
- Third, with respect to the innovation, the simulation tool developed can be used to evaluate innovative transport infrastructure, vehicles, and operational procedures.
- Forth, in relation to the use of game engines to create simulation tools, new game engines could be considered for the development of rail and terminal operations. The game engines provide a rich environment for engineering challenges. Simulation models can be developed for training train drivers and terminal operators using virtual/mixed reality technology. The potential of online multiplayer application can enhance the multi-stakeholder decision, and methods such as Delphi can be introduced in the multi-stakeholder decision to evaluate a consensus decision.
- Fifth, with respect to the use of the simulation tools considering multi-stakeholder decision, the theoretical framework can be applied for other software applications, (e.g., simulate urban planning, shopping centres, airports).

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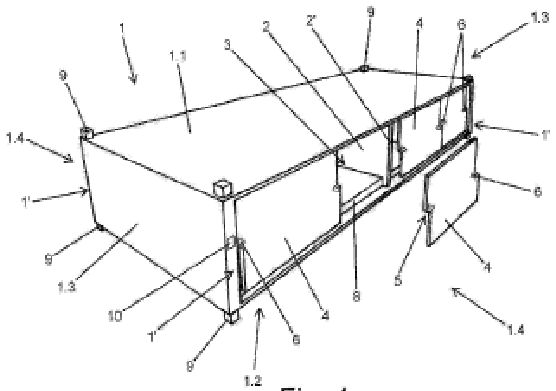

Fig. 1

(57) **Abstract:** Multi-compartmental intermodal container for storing and transporting freight, the multi- compartmental intermodal container comprising a body (1) with an interior space defined by a top wall (1.1), a bottom wall (1.2), two ends (1.3) and two laterals (1.4). The multi- compartmental intermodal container further comprises at least an internal wall (2) arranged for dividing the interior space into compartments (3); and at least a door (4) for providing access to the compartments (3).

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MULTI-COMPARTMENTAL INTERMODAL CONTAINER

Field of the invention

Present invention relates to an industry dedicated to intermodal transport of freight, and more particularly to the industry dedicated to manufacturing intermodal containers for storing and transporting the freight, such as any type of materials and products.

Background

Transport or shipping is essential economy and society. In order to reduce dependency on oil and to cut greenhouse gas emissions from the transport sector, it is vital to promote more efficient transport systems or modes, such as railways.

A variety of different containers are widely used in different modes of transport, from ship to rail to truck, without unloading and reloading their cargo. In many countries the containers are becoming the most common commodity transported by railways. For example, British intermodal rail freight activity has increased by 62% between 1998/99 and 2010/11.

Such containers come in a variety of standard sizes including, for example, ISO (International Standards Organization) containers with a length of 20 ft (approx. 6.10 meter), this is of 1 TEU (Twenty-foot Equivalent Unit), 24 ft and 40 ft (2 TEU), and domestic or non-ISO containers of 45 ft, 48 ft and 53 ft of length. Said containers, the ISO and non-ISO containers, are also known as intermodal containers, and cargo or freight containers.

There exist numerous Patents related to the intermodal containers such as US Patent No. 3,034,825 (L. A. Harlander et al.), US Patent No. 3,085,707 (K.W. Tantlinger), US Patent No. 3,646,609 (Bodenheimer), US Patent No. 4,212,405 (Schmidt) and US Patent No 5,248,051 (Yurgevich et al.).

Most common height for the intermodal containers is 8 ft 6 in (approx. 2.59 m) for 1 and 2 TEU intermodal containers, but there are also used the intermodal containers of 1 TEU with the height of 9 ft 6 in (approx. 2.90 m) and the height of 4 ft 3 in (approx. 1.30 m), which are known as "High Cubes" and "half height containers", respectively, in intermodal transport of freight. For the non-ISO intermodal containers the most common height is also the height of

8 ft 6 in. Most common width for the intermodal containers is of 8 ft (approx. 2.44 m).

Although there is a range of different sizes for the conventional intermodal containers, frequently the freight or shipment is not large enough to fill one of said conventional intermodal containers. This results in an inefficient use of interior space of the conventional intermodal containers and, therefore, in a cost higher than which would correspond if the interior space of the conventional intermodal containers were more adapted to required space by the freight. This, at the same time, involves a more expensive final cost of products and materials stored and transported in said interior spaces of the conventional intermodal containers.

Summary of the invention

Present invention relates to a multi-compartmental intermodal container for storing and transporting freight, the multi-compartmental intermodal container comprising a body with an interior space defined by a top wall, a bottom wall, two ends and two laterals. The multi-compartmental intermodal container further comprises at least an internal wall arranged for dividing the interior space into compartments; and at least a door for providing access to the compartments.

The multi-compartmental intermodal container can comprise three of the internal walls. Additionally or alternatively, at least one of the internal walls is arranged transversally with respect to the laterals.

The multi-compartmental intermodal container can comprise one of the doors for each of the compartments. The multi-compartmental intermodal container can additionally comprise another of the doors for each of the compartments such that it comprises two of the doors for each of the compartments, one of the doors being disposed facing the other.

The multi-compartmental intermodal container can comprise closing means for fixing at least one of the doors to a lateral edge of one of the internal wall. Additionally or alternatively, the multi-compartmental intermodal container can comprise a height of between 2 ft 6 in and 3 ft 2 in.

The top wall and the bottom wall of the container have corresponding structures configured so that such containers are stackable on top of another of such container, and/or the bottom wall of the container is configured for being placeable onto an upper wall of conventional intermodal containers so that the multi-compartmental intermodal container is stackable on top of the conventional intermodal containers.

The multi-compartmental intermodal container can comprise an energy source for providing energy to at least one of the compartments; at least an electronic system for management of information related with transport of the freight contained in one or more than one of the compartments; and/or corner castings, the corner castings including conventional twistlocks.

The multi-compartmental intermodal container is made of composite materials or polymers. The polymer is selected from polyolefin, polyallomer, glass fiber, carbon fiber, polyethylene and polypropylene.

Brief description of the drawings

Figure 1 is a perspective view of a multi-compartmental intermodal container object of the present invention, according to a preferred embodiment.

Figure 2 shows a door for closing a compartment of the multi-compartmental intermodal container of figure 1.

Figure 3 shows a lateral view of the multi-compartmental intermodal container of figure 1, four of the doors closing four of the compartments.

Figure 4 shows three of the multi-compartmental intermodal containers of figure 3 stacked on top of one another and a conventional intermodal container.

Figure 5 shows a railway with a rail wagon with two of the multi-compartmental intermodal containers stacked on top of two of the conventional intermodal containers and another rail wagon with two groups of three of the multi-compartmental intermodal containers stacked on top of one another.

Detailed description

Present invention relates to a multi-compartmental intermodal container. This intermodal container comprises a body (1) defined by a top wall (1.1), a bottom wall (1.2), two ends (1.3), and two laterals (1.4), such that an interior space is defined. Four corners (1') laterally connect the two ends (1.3) with the two laterals (1.4), such that the corners (1') laterally connect one of the ends (1.3) with one of the laterals (1.4).

Additionally, the multi-compartmental intermodal container comprises a number of internal wall (2). Preferably, the number of the internal walls (2) is three, as it is shown in figure 1. But, the number of the internal wall (2) can be one, two, four, five or any other number.

Said internal walls (2) are arranged such that the interior space is divided into compartments (3). Preferably, the internal walls (2) are arranged transversally with respect to the laterals (1.4), and more preferably, the internal walls (2) are arranged perpendicularly with respect to the laterals (1.4). Width of the multi-compartmental intermodal container becomes length or depth of the compartments (3).

The multi-compartmental intermodal container further comprises two door (4) for providing access to each of the compartments (3), each of the doors (4) being disposed in correspondence with one of the laterals (1.4), one different from the other. Figure 2 shows an example of these doors (4). In this case, when the multi-compartmental intermodal container comprises three of the internal walls (2), it also comprises eight of the doors (4), four of them at each of the laterals (1.4).

Loading and unloading operations are possible in a more flexible manner by being the doors (4) disposed in correspondence with the laterals (1.4). The ends (1.3) are preferably walls closing the multi-compartmental intermodal container. As an example, some of the multi-compartmental intermodal containers can be loaded and unloaded simultaneously they being disposed on rail wagons disposed consecutively.

As an alternative, the multi-compartmental intermodal container can comprise only one of the doors (4) for providing the access to each of the compartments (3). In this case, the access to the compartments (3) is preferably provided only by one of the laterals (1.4). As another alternative, one of the doors (4) can provide access to more than one of the compartments (3).

The doors (4) comprise a cut (5) of special design that supposes a discontinuity or change in vertical extension of lateral parts of the doors (4). The corners (1') also comprise the cuts (5), which in this case suppose a discontinuity or change in vertical extension of corresponding sides of the corners (1'). Each of the cuts (5) is complementary to the cut (5) located adjacent to it. In this way, the doors (4) are configured for coupling to the door (4) or the corner (1') laterally adjacent to them. These cuts (5) have a section (5') angled with respect to the vertical extension of the lateral parts of the doors (4) or the vertical extension of the corresponding sides of the corners (1'). The cuts (5) by means of said sections (5') improve coupling or closure of the doors (4).

The multi-compartmental intermodal container further comprises closing means (6) for closing the doors (4). The closing means (6) in turn comprise mechanical, magnetic or electronic devices for closing the doors (4). Said closing means (6) are located in the cuts (5), and more specifically in the section (5') of the cuts (5) for closing the doors (4) by fixing them to lateral edges (2') that have the internal walls (2).

The multi-compartmental intermodal containers and the doors (4) are configured so that the doors (4) are removable by being opened upwardly by means of hinges (not shown in the figures) connecting the doors (4) to the top walls (1.1). Alternatively, the multi-compartmental intermodal containers are configured so that the doors (4) are removable by being opened laterally by a first displacement outwardly with respect to the interior space and a second displacement parallel to the interior space. This alternative is preferably carried out the doors (4) being contained within outside perimeter of the multi-compartmental intermodal containers; this is, without protruding from the top wall (1.1) according to a view from above of the multi-compartmental intermodal container. This is due to the doors (4) are arranged inwardly with respect to a non-visible plane containing edges of the top wall (1.1) and the bottom wall (1.2).

Freight contained in the multi-compartmental intermodal container can correspond to a same owner having the freight distributed into some or all the compartments (3). Total volume of the freight can be formed by partial volumes because the freight comprises boxes, devices, machines or good, this is different units that are independent from each other. In this way, the freight can be distributed into the compartments (3) such that fixing operations for storing and transporting the freight are improved and simplified.

Alternatively, the freight contained in the multi-compartmental intermodal container can correspond not to the same owner, the freight of each of the owners being distributed in one or more than one of the compartments (3). In this way, cost for storing and transporting the freight is reduced for each of the owners.

Sometimes, it is highly recommended that the freight or a part of the freight to be stored and transported in a separated way. This can be, for example, because the freight comprises perishable products, chemical products or toxic products. At the same time, this type of freights, or of any other type, cannot fill a conventional intermodal container (7) by themselves. In these cases, the freights can be stored in the compartments (3) adequately separated. In the interior space of the compartments (3) undesired movements of the freights are clearly more restrained, which is especially interesting in case of the transport of the chemical products, the toxic products or delicate products.

The multi-compartmental intermodal containers comprise an energy source (8) for providing energy to the compartments (3). The energy source (8) comprises an energy generator or an energy storage device, such as a battery. This allows artworks, the perishable products, or any other product to be maintained in better conditions during the storing and transporting. In this way, for example, the compartments (3) can be refrigerated or heated. In this cases, the compartments (3) are accordingly configured such that the cool or the heat are maintained within them. Additionally, by means of the energy source (8), electronic devices can be transported they being switched on at all times.

As examples, to load or unload the freights a shipper can use regular pallet such as Euro Pallet (1000 x 1200) or special boxes for the freights with special needs such as refrigerated freights.

The bottom wall (1.2) has a form and dimensions which correspond to those of the top wall (1.1). The top wall (1.1) and the bottom wall (1.2) of the multi-compartmental intermodal container have corresponding structures configured so that they are stackable. Additionally or alternatively, the bottom wall (1.2) has the form and dimensions which correspond to those of upper walls (7.1) of the conventional intermodal containers (7). The bottom wall (1.2) of the multi-compartmental intermodal container is configured for being placeable onto the upper wall (7.1) of the conventional intermodal containers (7) so that the multi-compartmental intermodal container is stackable on top of the conventional intermodal containers (7).

The multi-compartmental intermodal container preferably also comprises corner castings (9) configured for allowing to be stackable while their positioning is blocked such that they are maintained stationary. For the last, the corner castings (9) include conventional twistlocks. The twistlocks allow transshipment of the multi-compartmental intermodal containers on terminals. The twistlocks provide an easy handling when are elevated for example by means of gantry cranes or sidelifters.

The multi-compartmental intermodal container comprise a separation distance between the top wall (1.1) and the bottom wall (1.2), this is a height, preferably of between 2 ft 6 in and 3 ft 2 in, more preferably of between 2 ft 9.8 in and 3ft 1.8 in, and further more preferably of 3 ft. This fact provides an easier handling and a better optimization of the interior space for the freights that do not fill adequately and efficiently the conventional intermodal containers (7). The undesired movements of the freight are even more restrained due to said height of the multi-compartmental intermodal container.

As an example of use of the invention, according to loading gauges of GB, one of the multi-compartmental intermodal containers is stackable on top of one of the conventional intermodal containers (7) so that a railway can transport them in compliance with gauge W10. For this option, both said containers can be stacked in regular or low floor flat wagons. Another option, also in compliance with the gauge W10, the railway can transport three of the multi-compartmental intermodal containers stacked on top of each other. Both options are shown by two rail wagons included in the figure 5. Described both options for the gauge W10 are also possible to be achieved in compliance with gauge W8 if the rail wagons are the low floor flat wagons.

In addition to metallic materials employed for manufacturing the conventional intermodal containers (7), other materials can be employed for manufacturing the multi-compartmental intermodal container. In this way, the multi-compartmental intermodal container comprises non-metallic materials, they comprising composite materials or polymers. The polymers are preferably selected from polyolefin, polyallomer, glass fiber, carbon fiber, polyethylene and polypropylene. The use of mentioned materials derivate in lower manufacturing costs, a high weight reduction, etc.

Each of the internal walls (2) provides an additional rigidity to the multi-compartmental intermodal container. Pressure or compression strength is increased by the internal walls (2). For example, a possible reduction in the pressure or compression strength due to a replacement of the metallic material by said non-metallic material in the manufacturing is compensable by said internal walls (2).

The multi-compartmental intermodal container further comprises electronic systems (10) for management of information related with the transport of the freight, this is for collecting and interacting with the information related with the transport of the freights. Additionally, opening and closing of the doors (4) can be managed due to the electronic systems (10) are electro-mechanically connected to the closing means (6).

Preferably, one of the electronic systems (10) is disposed in the multi-compartmental intermodal container, it being associated to one or more than one of the compartments (3), such as to all of the compartments (3). Alternatively, for each of the compartments (3) there is disposed and associated one of the electronic systems (10). For both options, the information related with the transport of the freight contained in each of the compartments (3) can be independently managed.

The electronic system (10) can comprise a data storage unit. The data storage unit is configured for collecting the data referred to the freight. Additionally, the data storage unit allows an interaction with or modification of the data collected. This data can be real-time data referred to the freight and transport modes or systems, such as the railways, trucks and ships. This data can be for example temperature and humidity inside of the compartments (3).

The electronic system (10) can comprise means of identification for giving or transmitting data referred to the freight contained into each of the compartments (3). The means of identification can comprise, for example, RFID or optical QR-Codes, which require a manual operation, or smart forklift trucks, which do not require direct intervention of human operators. Said means of identification allow operations usually carried out in terminals to be more rapidly done.

The electronic system (10) can comprise infrared vision devices for capturing of images. The infrared vision devices are infrared cameras and they are arranged principally for security reasons. By means of the infrared vision devices data referred to tracks according to which the transport systems are displaced for the transport of the freights is obtained. Said data is analyzed based on predefined local criteria or criteria stored on cloud computing, both according to characteristics of the track that are known.

The electronic system (10) can comprise a geolocation device. The geolocation device can optimize the analyze carried out according to the images captured by the infrared vision devices and/or support decisions from no operational entities, such as for example passengers and operators of government road or the track.

CLAIMS:

1.- Multi-compartmental intermodal container for storing and transporting freight, the multi-compartmental intermodal container comprising:

- a body (1) with an interior space defined by:
  - a top wall (1.1), a bottom wall (1.2), two ends (1.3) and two laterals (1.4);

characterized in that it further comprises:

- at least an internal wall (2) arranged for dividing the interior space into compartments (3); and
- at least a door (4) for providing access to the compartments (3).

2.- Multi-compartmental intermodal container according to claim 1, comprising three of the internal walls (2).

3.- Multi-compartmental intermodal container according to claim 1 or 2, wherein at least one of the internal walls (2) is arranged transversally with respect to the laterals (1.4).

4.- Multi-compartmental intermodal container according to any one of the preceding claims, comprising one of the doors (4) for each of the compartments (3).

5.- Multi-compartmental intermodal container according to any one of the preceding claims, comprising two of the doors (4) for each of the compartments (3), one of the doors (4) being disposed facing the other.

6.- Multi-compartmental intermodal container according to any one of the preceding claims, further comprising closing means (6) for fixing at least one of the doors (4) to a lateral edge (2') of one of the internal wall (2).

7.- Multi-compartmental intermodal container according to any one of the preceding claims, comprising a height of between 2 ft 6 in and 3 ft 2 in.

8.- Multi-compartmental intermodal container according to any one of the preceding claims, wherein the top wall (1.1) and the bottom wall (1.2) of the container have corresponding structures configured so that such containers are stackable on top of another of such container.

9.- Multi-compartmental intermodal container according to any one of the preceding claims, wherein the bottom wall (1.2) of the container is configured for being placeable onto an upper wall (7.1) of conventional intermodal containers (7) so that the multi-compartmental intermodal container is stackable on top of the conventional intermodal containers (7).

10.- Multi-compartmental intermodal container according to any one of the preceding claims, further comprising an energy source (8) for providing energy to at least one of the compartments (3).

11.- Multi-compartmental intermodal container according to any one of the preceding claims, further comprising corner castings (9), the corner castings (9) including conventional twistlocks.

12.- Multi-compartmental intermodal container according to any one of the preceding claims, further comprising at least an electronic system (10) for management of information related with transport of the freight contained in one or more than one of the compartments (3).

13.- Multi-compartmental intermodal container according to any one of the preceding claims, wherein the multi-compartmental intermodal container is made of composite materials or polymers.

14.- Multi-compartmental intermodal container according to claim 13, wherein the polymer is selected from polyolefin, polyallomer, glass fiber, carbon fiber, polyethylene and polypropylene.

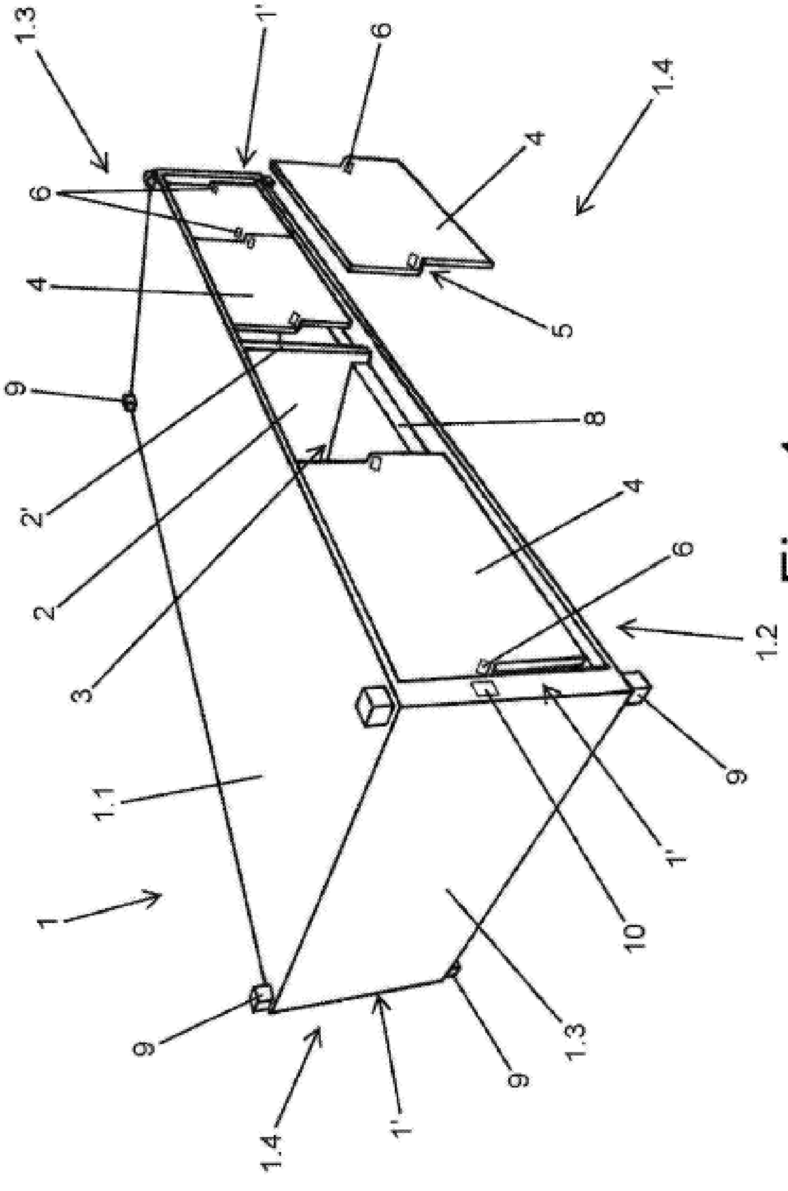

Fig. 1

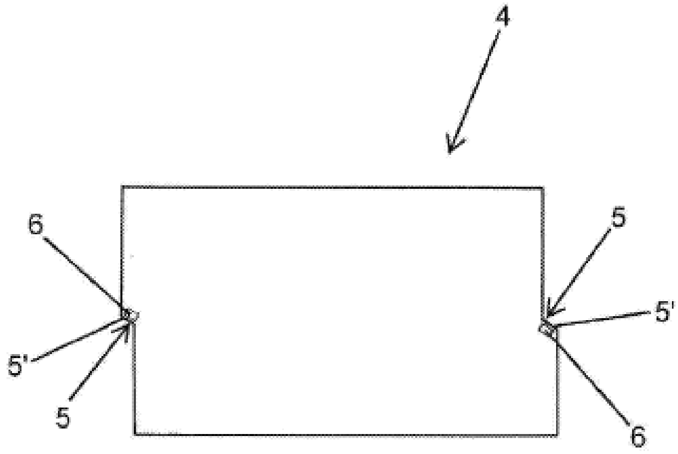

Fig. 2

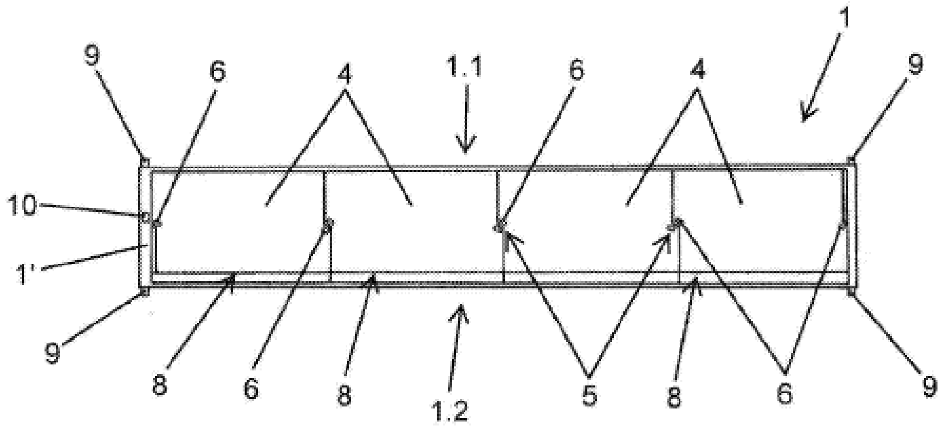

Fig. 3

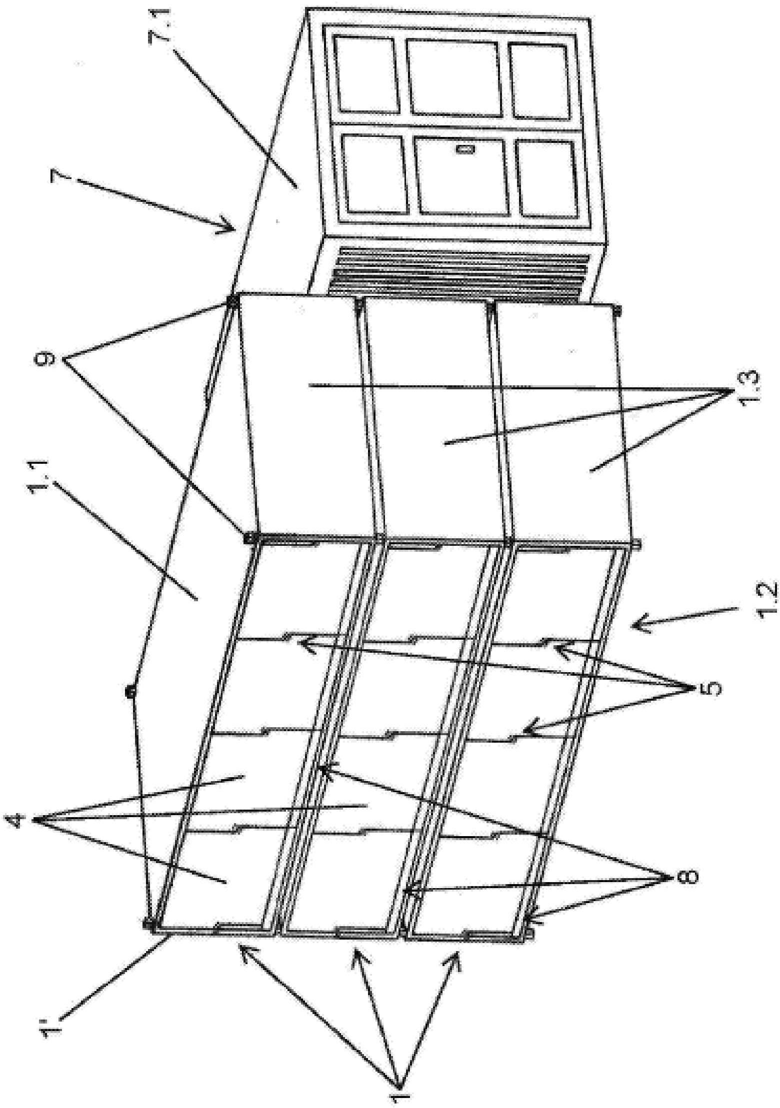

Fig. 4

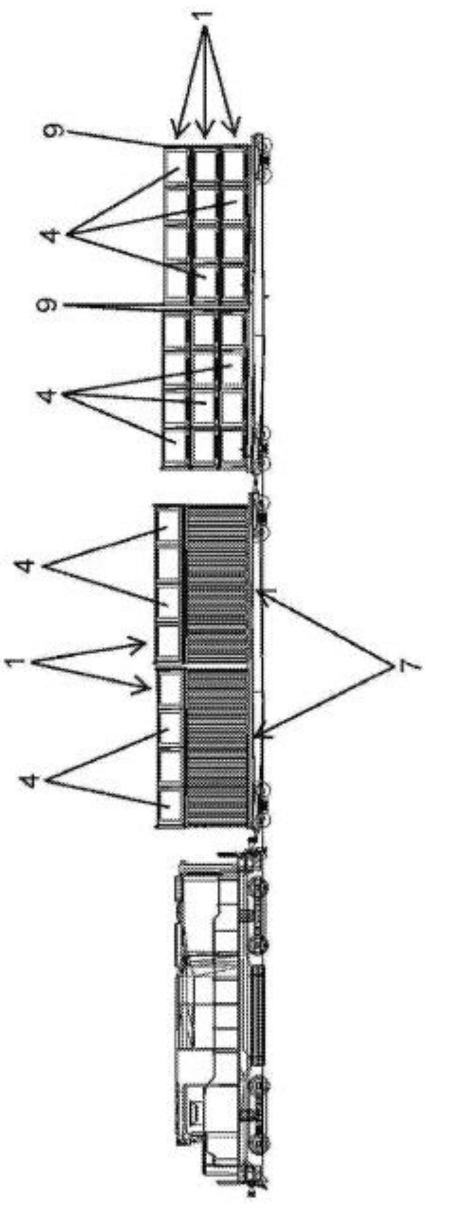

Fig. 5

INTERNATIONAL SEARCH REPORT

International application Nº PCT/IB2015/059188

A. CLASSIFICATION OF SUBJECT MATTER

B65D88/12 (2006.01), B65D88/10 (2006.01), B65D88/00 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B65D88/00, B65D88/10, B65D88/12, B65D90/00, B65D90/48, B65D90/54

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

GOOGLE PATENTS

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, ESPACENET

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claims Nº
X Y	US 20070210080 A1 (HOOPER ROBERT C [CA]) 13 de setembro de 2007 (2007-09-13) Abstract, [0018] [0049] [0050] [0056], figure 1 to 5, claims 1, 7	1, 2, 3, 4, 6, 8, 9, 11 10, 12, 13, 14
Y	US 2011247356 A1 (TNO [NL]) 13 October 2011 (2011-10-13) Abstract, [0011]	10
Y	WO 2014056087 A1 (TEKTRAP SYSTEMS INC [CA]) 17 April 2014 (2014-04-17) Abstract, all document	10
Y	US 2008073422 A1 (CHINA INT MARINE CONTAINERS) 27 March 2008 (2008-03-27) Abstract, All document	12

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority claimed

"T" later document published after the internationa filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvius to a person skilled in the art

"&" document member ot the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22/03/2016	01/04/2016

Name and mailing address of the ISA/**BR**	Authorized officer
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Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application N°
PCT/IB2015/059188

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claims N°
Y	US 2001038009 A1 (BOH ENVIRONMENTAL [US]) 08 November 2001 (2001-11-08) Abstract, [0083] ---	13,14

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application Nº
PCT/IB2015/059188

Patent documents cited in search report	Publication date	Patent family members	Publication date
US 2007210080 A1	2007-09-13	US 7591386 B2	2009-09-22
		CA 2580418 A1	2007-09-08
US 2011247356 A1	2011-10-13	CN 102216706 A	2011-10-12
		EP 2177849 A1	2010-04-21
		EP 2350543 A1	2011-08-03
		WO 2010047590 A1	2010-04-29
WO 2014056087 A1	2014-04-17	None	
US 2008073422 A1	2008-03-27	CN 101114353 A	2008-01-30
US 2001038009 A1	2001-11-08	AT 496837 T	2011-02-15
		AU 7700200 A	2001-04-30
		DE 60045582 D1	2011-03-10
		EP 1224127 A1	2002-07-24
		ES 2220240 T1	2004-12-16
		PT 1224127 E	2011-04-06
		US 6299008 B1	2001-10-09
		US 2004007572 A1	2004-01-15
		US 7185779 B2	2007-03-06
		WO 0123261 A1	2001-04-05

Form PCT/ISA/210 (patent family annex) (July 2009)

Annex_2

Rail Freight Interchange Simulation Tools Software Handbook

Introduction

The objective of this handbook is to provide the basic instructions in an user-friendly manner for anyone interested in the software packages developed in this thesis

This handbook is divided into three main sections in order to explain the main concepts involved in the different tools and providing a basic understanding of the software functions.

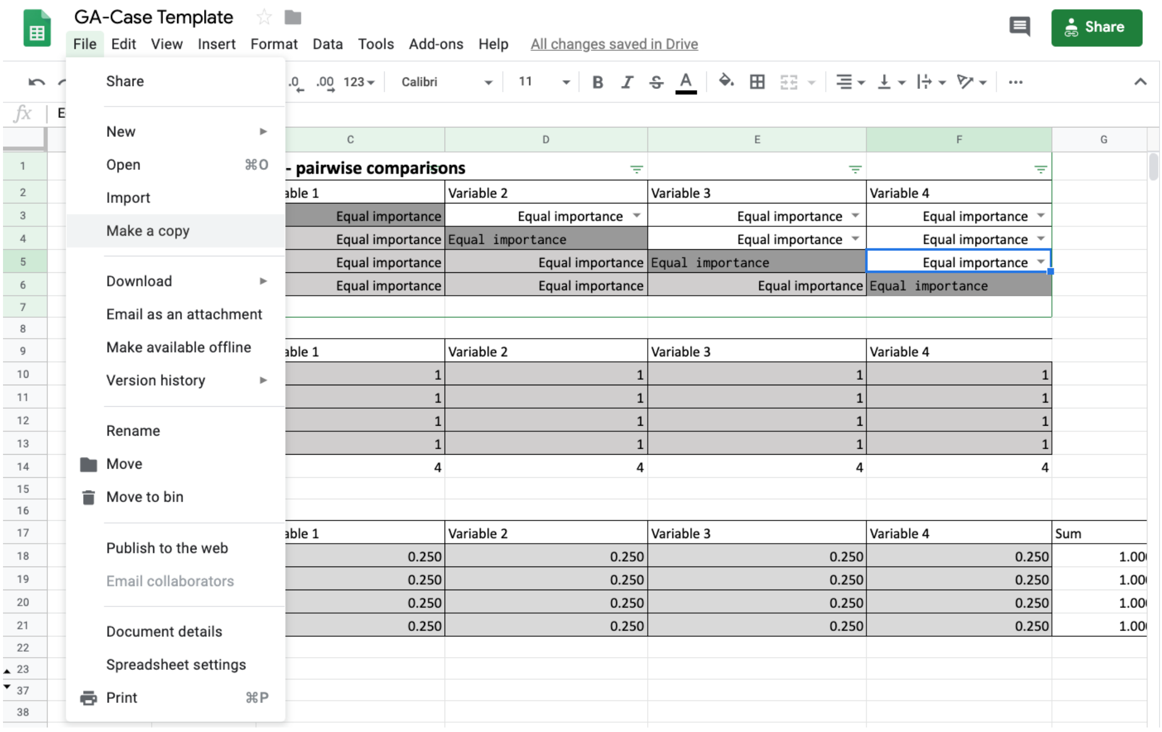
1- Multi stakeholders decision

1.1 OVERVIEW

The multi stakeholder decision tools is an application of the Analytic Hierarchy Process implemented in an online calculation environment to support multi-criteria decision making,

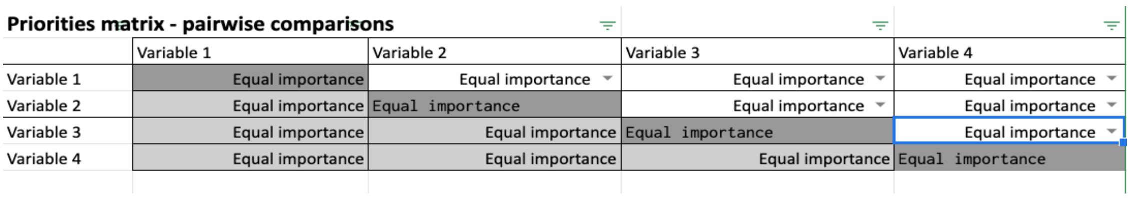
1.2 IMPLEMENTATION

The link presented in the thesis (https://goo.gl/cT5zZV) illustrate the online implementation of the AHP solution for the rail freight interchange study. However the user can easily adapt the implementation for other implementations making a copy of the spreadsheet (User Manual Figure 1)



User Manual Figure 1: Spreadsheet AHP configuration - Creating a copy

For using the AHP package the first step is the definition of the number of stakeholders and the number of decision drivers that will be used to compare the potential solutions (User Manual Figure 2)



Priorities matrix - pairwise comparisons

	Variable 1	Variable 2	Variable 3	Variable 4
Variable 1	Equal importance	Equal importance	Equal importance	Equal importance
Variable 2	Equal importance	Equal importance	Equal importance	Equal importance
Variable 3	Equal importance	Equal importance	Equal importance	Equal importance
Variable 4	Equal importance	Equal importance	Equal importance	Equal importance

User Manual Figure 2: Spreadsheet AHP configuration – changing the preference a copy

The implementation allow the user to change the relative importance of the main comparison matrix (white cells), the cells where the comparison is with the same variable (dark grey) are blocked and the value is always equal importance. When the value on the white cells are changes (e. variable 4 against variable 3) the value of the comparison of the inverted option (variable 3 against variable 4) is automatically filled (User Manual Figure 3)

Priorities matrix - pairwise comparisons				
	Variable 1	Variable 2	Variable 3	Variable 4
Variable 1	Equal importance	Equal importance	Equal importance	Equal importance
Variable 2	Equal importance	Equal importance	Equal importance	Equal importance
Variable 3	Equal importance	Equal importance	Equal importance	Strongly less important
Variable 4	Equal importance	Equal importance	Strongly more important	Equal importance

User Manual Figure 3: : Spreadsheet AHP configuration: Autocompleting

The numeric representation following Saaty method is completed as follow (User Manual Figure 4)

	Variable 1	Variable 2	Variable 3	Variable 4
Variable 1	1	1	1	1
Variable 2	1	1	1	1
Variable 3	1	1	1	0.2
Variable 4	1	1	5	1
	4	4	8	3.2

User Manual Figure 4: Spreadsheet AHP configuration: Numeric values conversion

For introduce more decision drivers the user can expand the existing cells making a copy of the cells of the comparison matrix.

	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variable 6	Variable 7
Variable 1	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance
Variable 2	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance
Variable 3	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance
Variable 4	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance
Variable 5	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance
Variable 6	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance
Variable 7	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance	Equal importance

User Manual Figure 5: : Spreadsheet AHP configuration: Expanding comparison matrix

The final output of the AHP implementation is the importance priority matrix showing the weight of each variable after the stakeholder preferences, 2- Genetic Algorithm Implementation

2.1 OVERVIEW

The Genetic Algorithm implementation look at the procedural generation of alternatives for the interchange problem. The heuristic creates a number of alternatives and thought the evolutive process select the highest fitted solutions for the problem.

2.2 IMPLEMENTATION

Similarity of the AHP, the GA implementation starts at the variables definition to consider for the problem. Generally each element of the rail freight interchange can present a number of different parameters and characteristics that could be used to compare among other options such as energy consumption, maintenance, operational costs, capacity, employment generation and several others.

For the implementation of the GA the most important characteristics of each element is put in the spreadsheet. The next step is understanding the optimization process. The GA implemented consider that the user want to maximize some criteria subject to some restriction, therefore the elements that are desirable to the user (e.g containers moved, storage capacity, employment generation) need to be balanced with the elements that need to be minimized (e.g operational costs, carbon emissions, energy consumption etc). The GA implementation balance the proportional value of the criteria to maximize (named in this work as efficiency) of all alternatives multiplied by the priority defined in the AHP implementation.

$$Eff_V = \sum_{i}^{N} (Pri_v\,(i).\,(\frac{V_{cost}}{V_{avar}}))$$

Where

Effv = Efficiency value for the objective function considering the user priority

Priv = Priority weighed by the AHP module

Vcost = Value assigned for each KPI (e.g. employment generation)

Vavar = Average value of the KPI

Similarly the constraints of the interchange are calculated considering the elements to be minimized. The costs are usually the main constraint applied in this work, however for future work an implementation considering carbon footprint is in development. Th3 constrains are calculated

$$Const_V = \sum_{i}^{N} (Pri_v\,(i).\,(\frac{C_{cost}}{C_{avar}}))$$

Constv = Constrain value for subject the objective function considering the user priority

Priv = Priority weighed by the AHP module

Vcost = Value assigned for KPIs that constrain the optimization (e.g. costs)

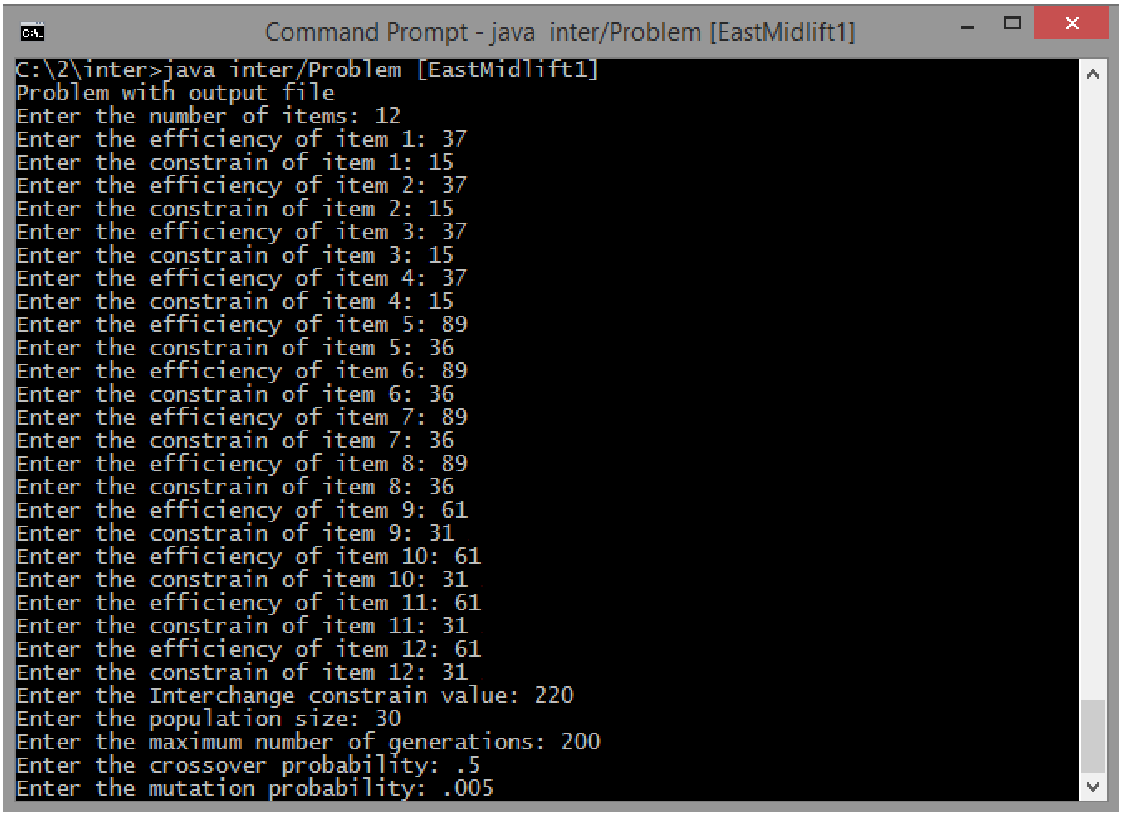
With these efficiency and constrains calculated considering the stakeholders priorities the GA package can be executed by the user. The software package ask the user the number of items to be compared. This number is the encoding of the alternatives in the gene representation.

The implementation of the GA in java allow the user to quick have access to a number of solutions for the given problem. The application is executed by the prompt command java **inter** (representing the name of the application) /Problem (representing the directory where the solutions are saved) and the name of the file to be saved.

The software starts asking the user the number of the items to be used on the simulation. This number represents the number of possible alternatives. Each one of those alternatives will be encoded in the genetic algorithm. In the example of the

East Midlands (User Manual Figure 6) the terminal simulated could receive up to 12 lifting equipment.

As can be seen the software asks the user the values of efficiency and constraints of each alternative



```
Command Prompt - java  inter/Problem [EastMidlift1]
C:\2\inter>java inter/Problem [EastMidlift1]
Problem with output file
Enter the number of items: 12
Enter the efficiency of item 1: 37
Enter the constrain of item 1: 15
Enter the efficiency of item 2: 37
Enter the constrain of item 2: 15
Enter the efficiency of item 3: 37
Enter the constrain of item 3: 15
Enter the efficiency of item 4: 37
Enter the constrain of item 4: 15
Enter the efficiency of item 5: 89
Enter the constrain of item 5: 36
Enter the efficiency of item 6: 89
Enter the constrain of item 6: 36
Enter the efficiency of item 7: 89
Enter the constrain of item 7: 36
Enter the efficiency of item 8: 89
Enter the constrain of item 8: 36
Enter the efficiency of item 9: 61
Enter the constrain of item 9: 31
Enter the efficiency of item 10: 61
Enter the constrain of item 10: 31
Enter the efficiency of item 11: 61
Enter the constrain of item 11: 31
Enter the efficiency of item 12: 61
Enter the constrain of item 12: 31
Enter the Interchange constrain value: 220
Enter the population size: 30
Enter the maximum number of generations: 200
Enter the crossover probability: .5
Enter the mutation probability: .005
```

User Manual Figure 6: Genetic Algorithm implementation demo

After completing all alternatives efficiency and constraints values the user needs to inform the terminal constraint value. The alternatives will be selected in order to maximize the efficiency but under the maximum constraint assigned here.

After the constraint value the users need to inform the initial population which is the number of solutions in the first generation. This generation will have the genetic code (gens) transferred to the following generation, a small number here can result in faster simulation, however a limited number of diversities. Ideally the population number needs to be sufficient to allow the evolution process.

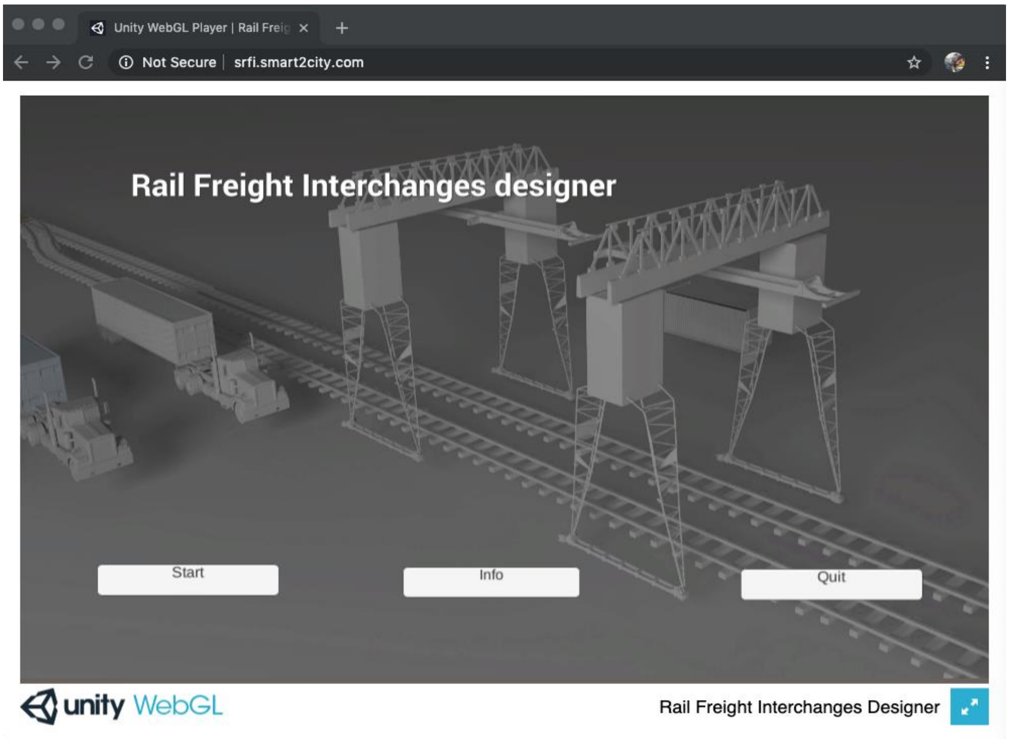
After the population the user need to inform the maximum population number, this value represents the limit of the evolution process (stop criteria). After the population number the crossover probability are required to allow the software to use the crossover process. The crossover represents the number of genetic materials transferred from one generation to another, higher crossover value means higher similarities between generations, therefore the evolution process tends to be slower. On the other hand size smaller crossover causes impact on the variability of the genes. After some trials with the software the best results was found with values between 0.4 and 0.6 (40% to 60%). The last value to be informes is optional and represents the mutation process. In the mutation some genes changes the value at a random point. In simulations with the software values higher than 2% resulted in instability in the process not delivering effective results even after several generations due the mutation porcess.

After all those values informed the software execute the genetic evolutionary process and presents the graph with the mean results of each generation. All the genetic code are also recorded in a document text to allow the user later understand the process.

3- Interchange designer

3.1 Overview

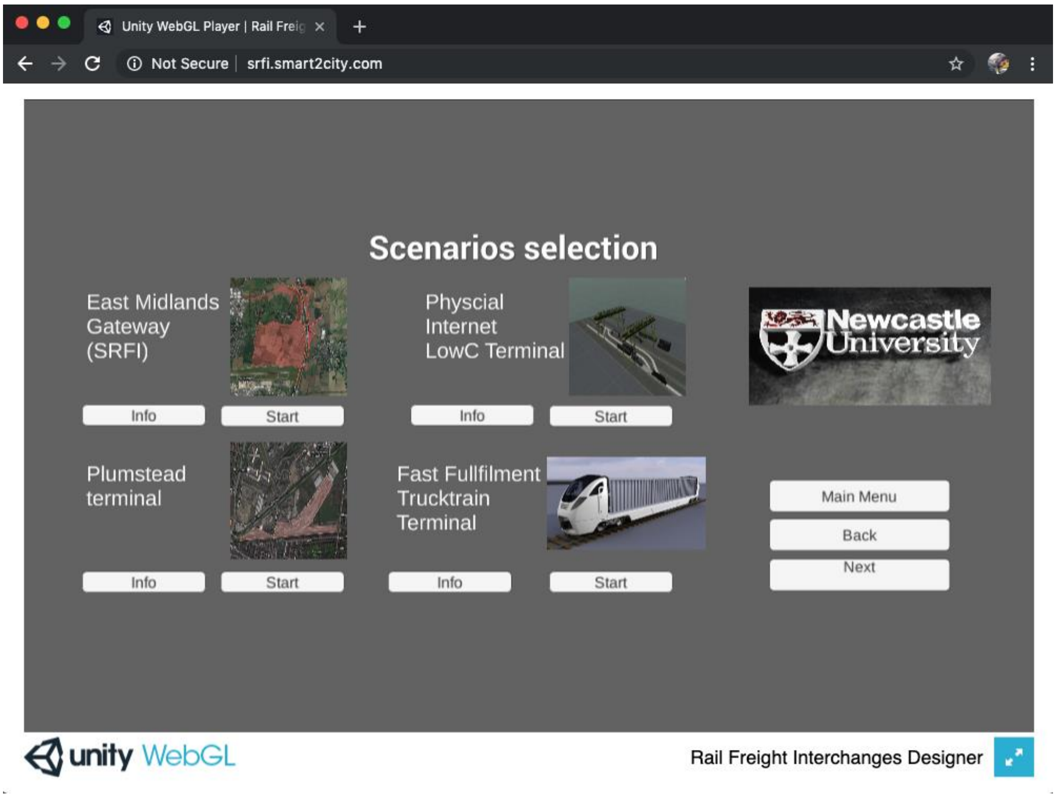
The interchange designer was created to offer highly realistic interchange designer experience playing the scenarios created with the SRFI designer tool. The first step to use the SRFI is to access the website srfi.smart2city.com where the webgl version of the software is hosted (User Manual Figure 7).



User Manual Figure 7: SRFI designer: online execution

As can be seen the application allow the user to gain more information about the application or start the scenarios.

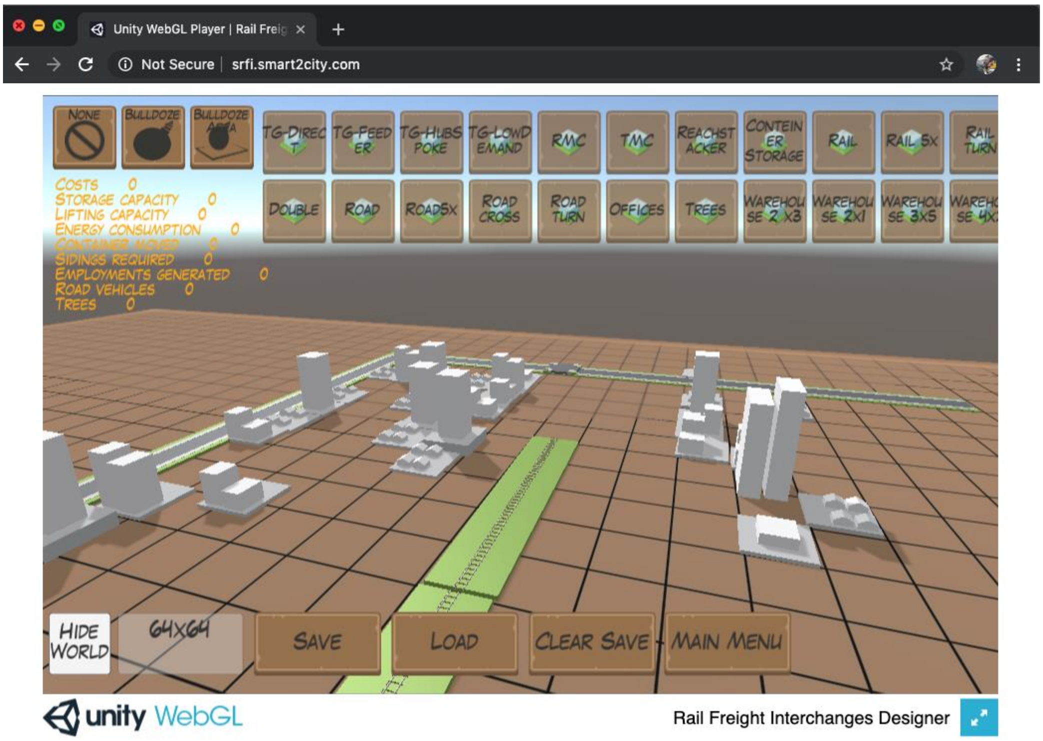
The four scenarios described in the thesis are available online with the respective information



User Manual Figure 8: Scenario selection

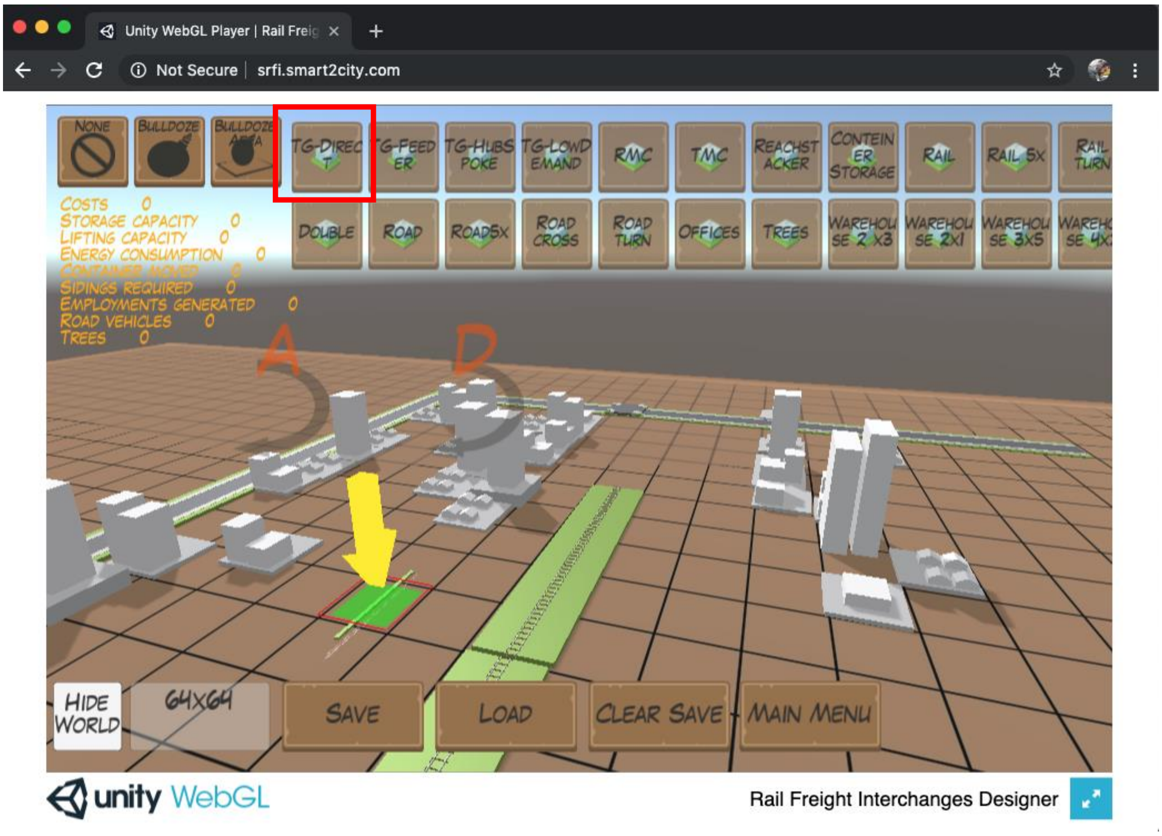
3.2 Implementation

The first example of the implementation (East Midland Gateway scenario) was created to illustrate a visualization of Strategic Rail Freight Interchanges, therefore the scenario includes several warehouse configurations, offices , road tracks and rail track (User Manual Figure 9). Another option for the use is the creation of the different transport demands.



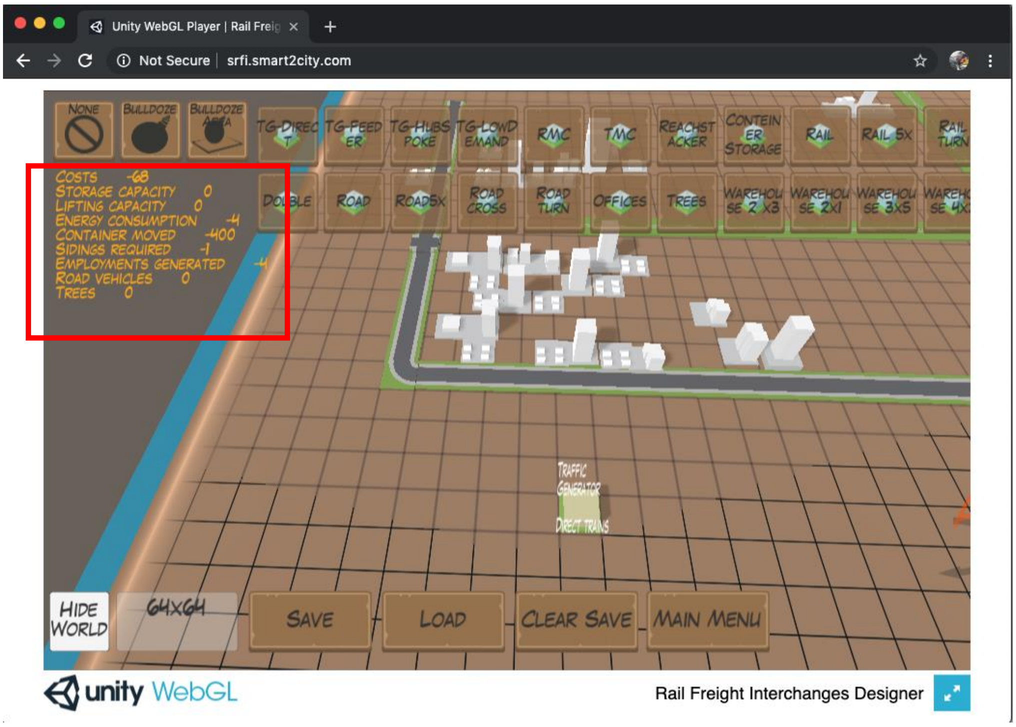
User Manual Figure 9: Selecting infrastructure

For instance after clicking in the first icon the software load in the memory the direct train demand configuration. The user now is allowed to deploy the direct train demand generator. For deploying a yellow arrow illustrate for the user where the transport demand will be placed and a green square show in each square of the map it will be placed (User Manual Figure 10)



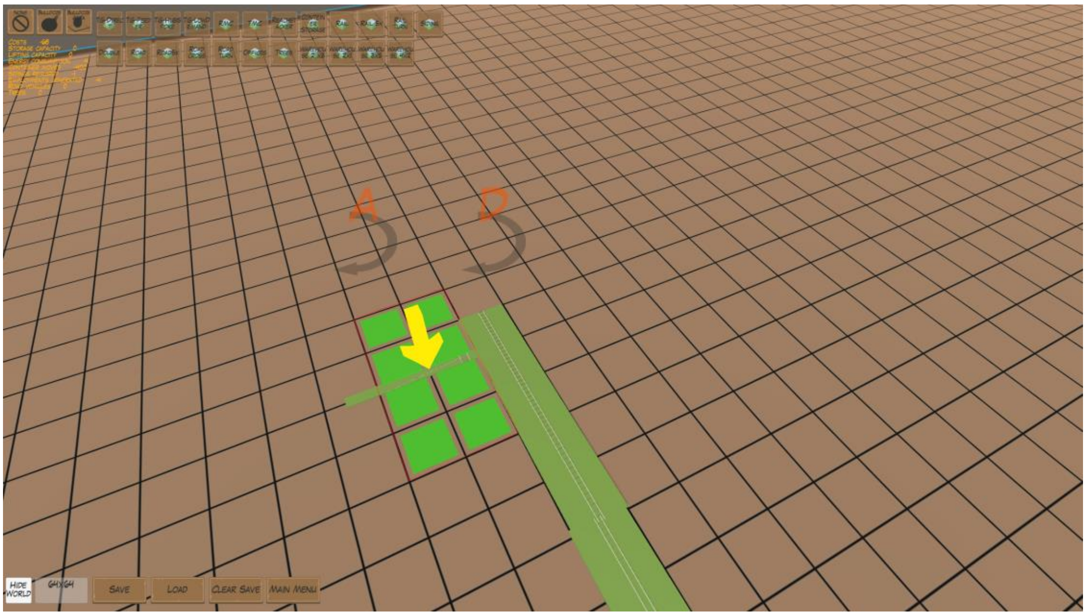
User Manual Figure 10: Placing infrastructure in the map

After deploying the direct trains traffic generator all the value assigned for the variables related to the direct train demand generator are transferred to the general indicators (User Manual Figure 11).

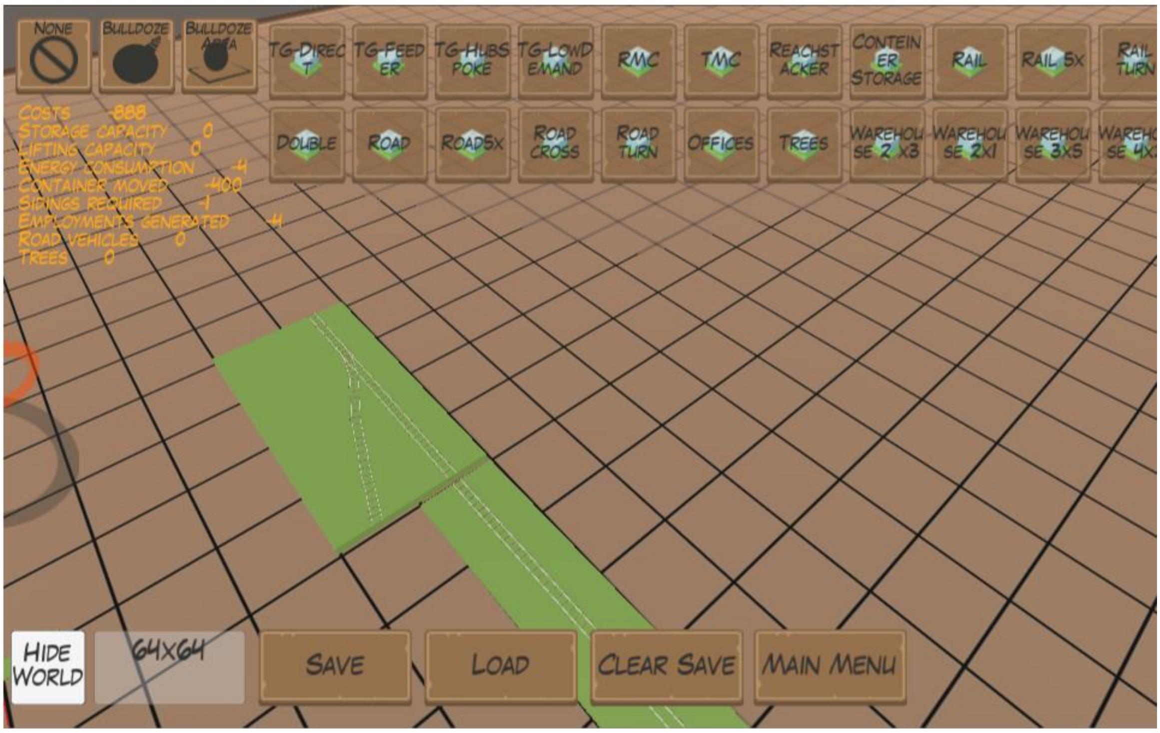


User Manual Figure 11: Output of the infrastructure deployed

Now as a new siding is required. The user can create a new siding for the interchange clicking on the last icon in the first line (User Manual Figure 12 and User Manual Figure 13).

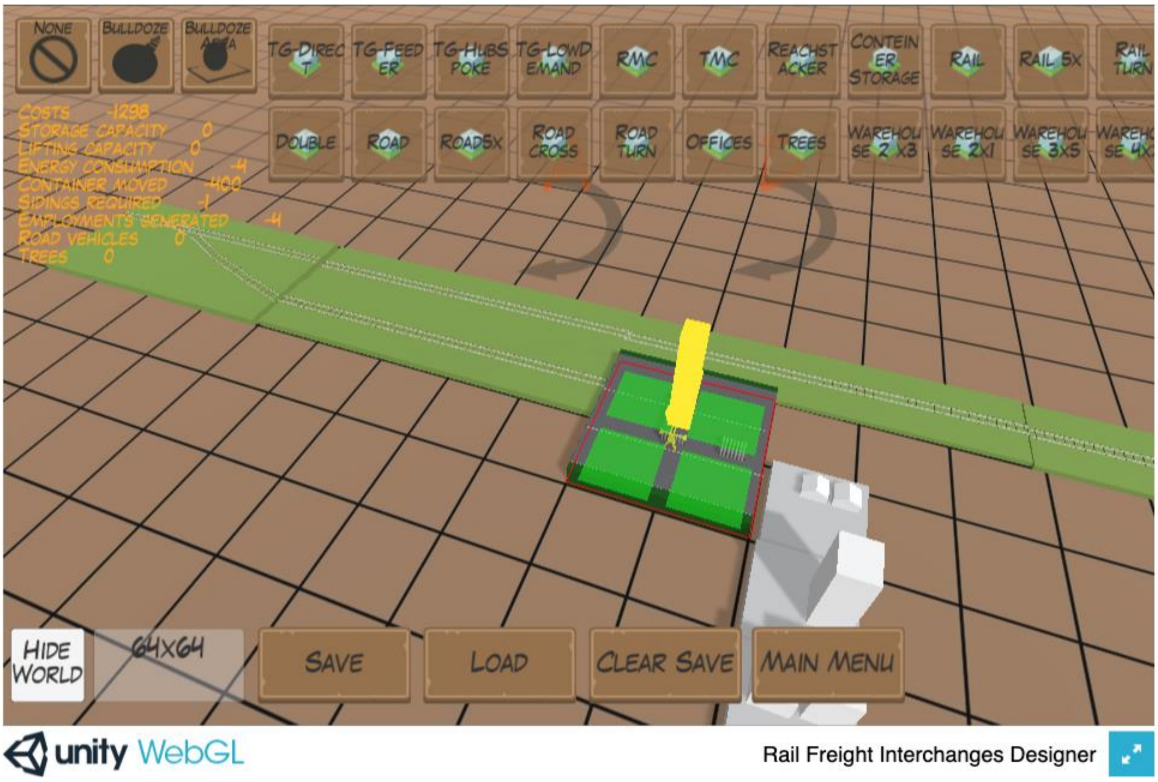


User Manual Figure 12: Placing sidings



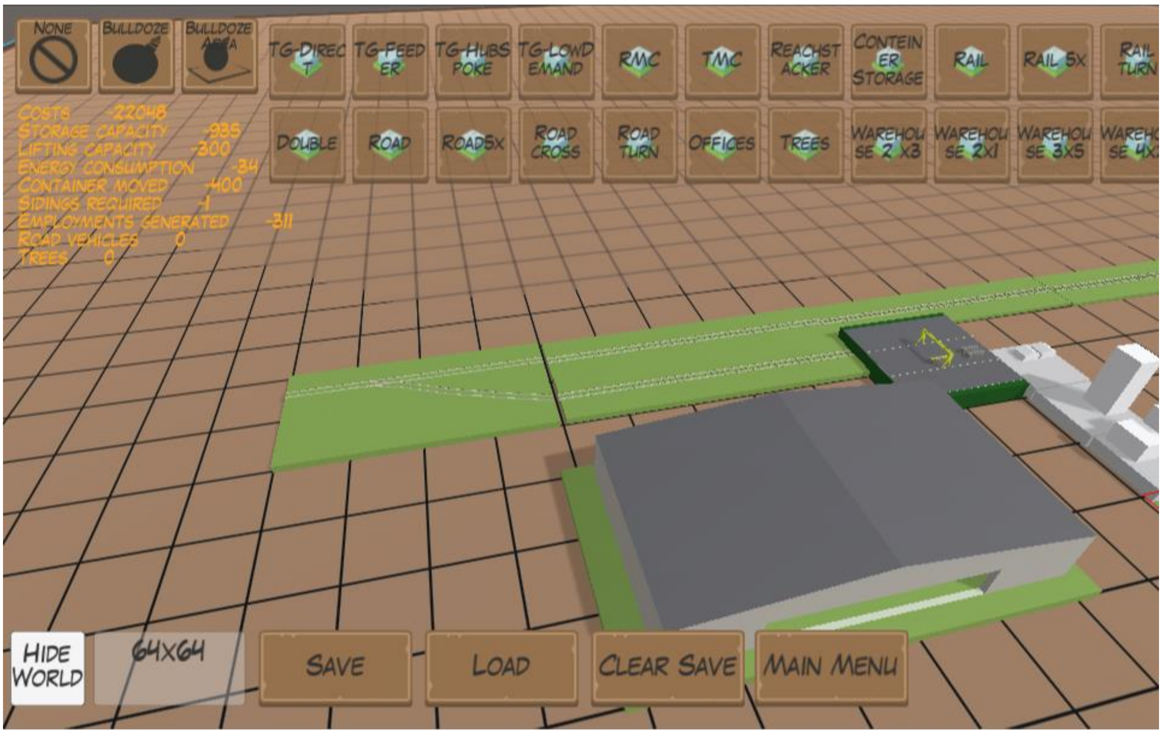
User Manual Figure 13: Siding deployed

With the first siding deployed the user now are able to expand the line of the interchange and deploy the transshipment equipment User Manual Figure 14



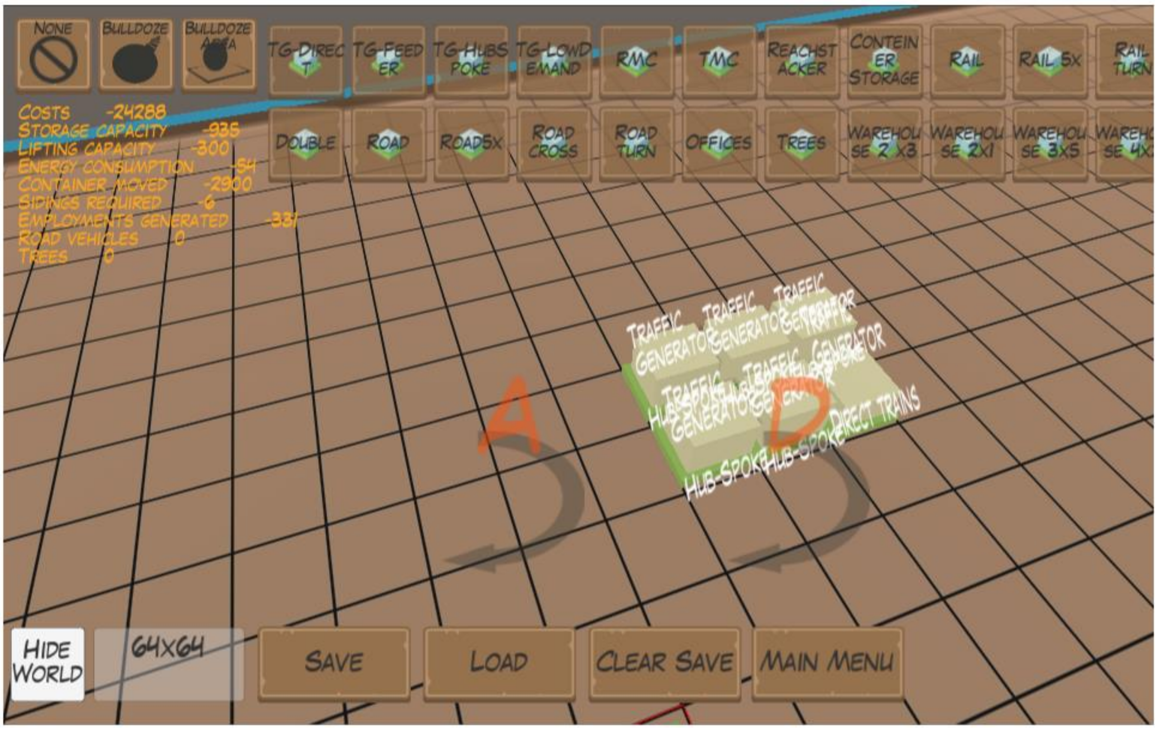
User Manual Figure 14: Placing transshipment equipment

With the transshipment equipment deployed (e.g rail mounted container in the picture) the user can place the warehouse facilities and container storage facilities (User Manual Figure 15)



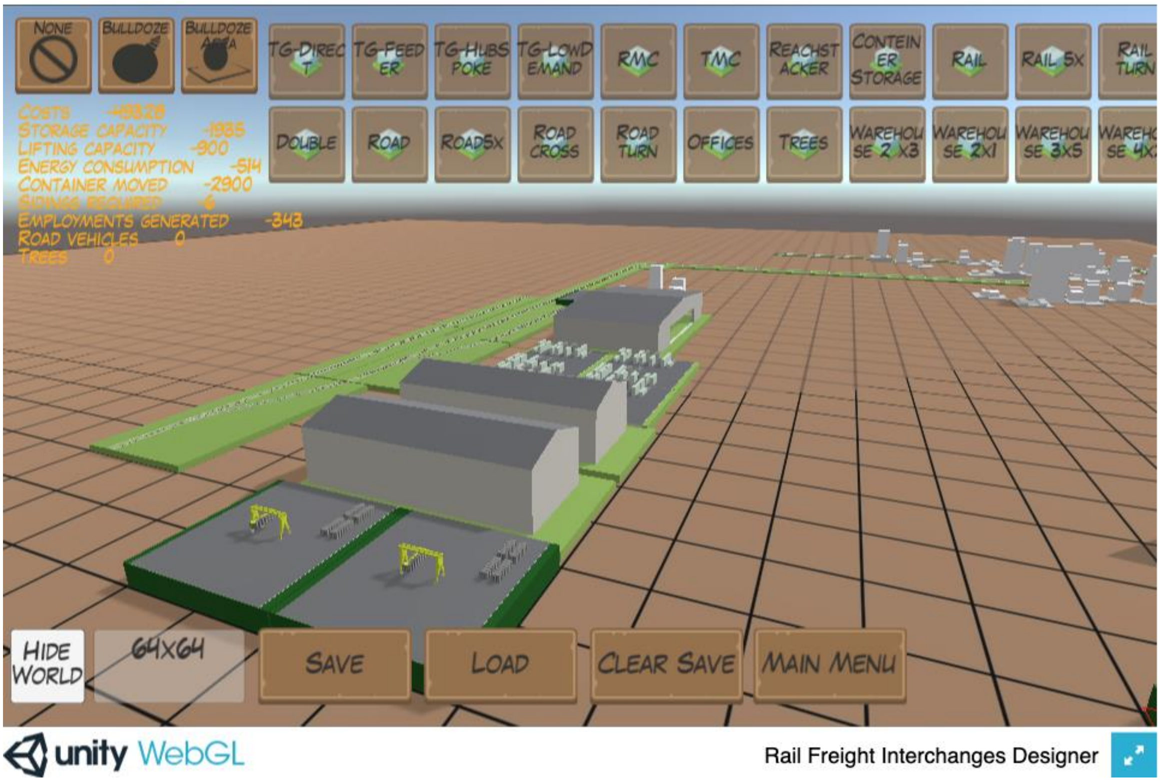
User Manual Figure 15: Placing warehouse

As the SRFI demangs grows the user needs to create additional traffic demand generators (e.g 5 HUB spoke demand generators User Manual Figure 16)



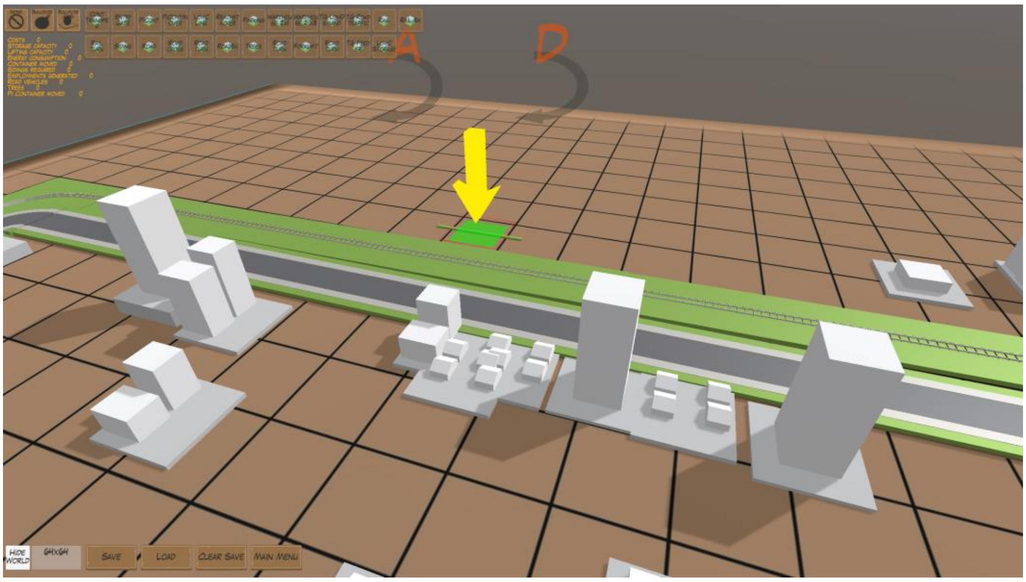
User Manual Figure 16: Placing Traffic generators

With the additional demand more warehouse transshipment and container storage will be required. The user can place the infrastructure clicking on the icons and selecting where to place the infrastructure (User Manual Figure 17).



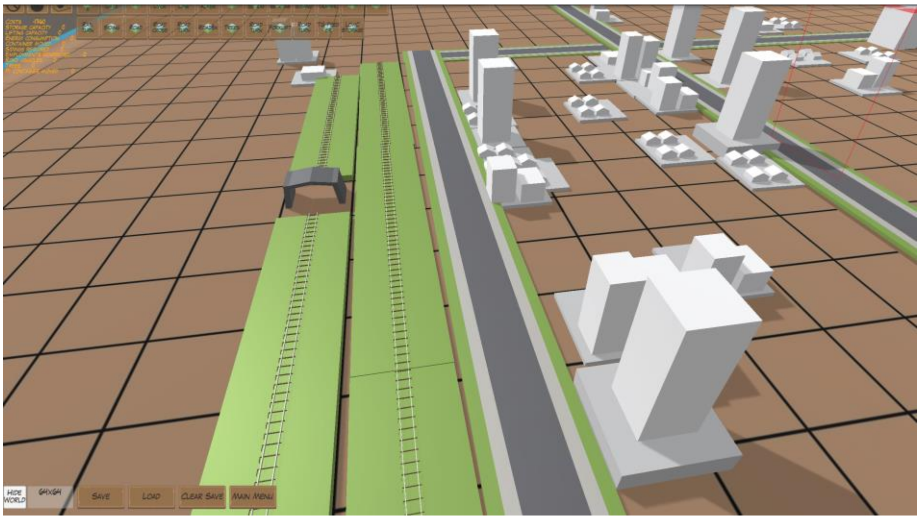
User Manual Figure 17: Placing extra infrastructure

The PI container interchange scenario was created to illustrate the use of the software considering PI terminal concept. The model includes other transshipment methods and the low traffic demand generator option (User Manual Figure 18)



User Manual Figure 18: Placing Low demand traffic generator

For this scenario, the first step is the creation of the transport demand placing the traffic generators and the required sidings for the interchange zone. Next the user needs to deploy the entry gate infrastructure (second icon User Manual Figure 19)



User Manual Figure 19: Placing entry gate

Next the user can place the Pi container movement (4th icon in the first line) or the Container transfer equipment (first icon User Manual Figure 20)

User Manual Figure 20: Placing Pi containers movers

All the scenarios created allows the user to save and load the configuration to compare different design alternatives. With the clear save the user can create a new version of the scenario.