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Redesigning A Commuter Rail System To Accommodate Passengers With Special Needs

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Declaration:

I declare that this dissertation is my unaided work and that it was not previously submitted at any institution for a degree or examination. This dissertation is being submitted at the Vaal University of Technology for Master's Degree in Industrial Engineering.

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(Signature of Candidate)

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Abstract

In South Africa, the provision of equitable and accessible public transport is still in the early stage of development and growth. PRASA has adopted programmes that drive and promote the implementation and integration of a universal design that should meet the varying requirements of its customers. PRASA acknowledges that its facilities should be focused on the delivery of public service that acts as a catalyst and enabler within South Africa in overcoming differentiation in gender, race, income, opportunity and mobility.

Facilities' managers and especially rail managers, through facilities planning, should provide proactive service delivery to its stakeholders. In South Africa, the majority of train stations are not designed to cater for persons with special needs. Therefore, these facilities must comply with national imperatives; resulting in a need to design new facilities or redesign current train stations' facilities so as to accommodate the diversity of human characteristics within the population, as a whole, in order to promote equal access to services and opportunities for persons with disabilities as expected in all spheres of government. This means that there are dynamic and heterogeneous elements that should be controlled in the commuter rail system design.

The redesigning of some train stations had been undertaken and improvements achieved at some train stations e.g. Gautrain. The issue that arises is that there cannot be a one-to-one transfer of model to design another facilities. This is due to the constraints of space, monetary costs and information on customers or level of activeness in the facility. Companies don't always have a lot of money at their disposal making money to become an issue. If there's an abundance of space then one can design the train layout the way he/she wants. However this is not always the case and therefore, the available space has to be planned accordingly. Furthermore, one needs to know information on (the number of) their customers in order to plan and be able to meet their requirements.

This project proposes the use of an improved flow-pattern measurement technique (i.e. integration of techniques), specifically improved From-To-Chart techniques, to assess the efficiency of the current layout while considering the constraints of variables expectations from customers and variable rewards for rendering services to different types of customers. An improved and effective layout was then proposed. The efficiency of the proposed new layout was compared with that of previous layout so as to ascertain on stakeholders' confidence. Simulated Annealing was also used to compare different peak periods and their efficiencies so as to decide on the layout that is suitable for the commuter rail system under the different peak scenario. The Direct Clustering Algorithm was furthermore employed to try to group facilities that render similar services into cells so as to minimise movement or material handling.

Results revealed that a flexible train station layout whose flow pattern can be regularly adjusted to minimize costs and to accommodate the ever-increasing expectations should be adopted. It is hoped that station managers who adopt such guides will improve on customer's expectations.

LIST OF PUBLICATIONS

1. **T Bele, Benga EBB and TB Tengen (2018),** *A Simulation Annealing Approach to Determine the Effective Train Station Layout with Different Peak Periods,* in proceedings of 29th Annual SAIIE conference held 24-26 October 2018 at Spier, Stellenbosch, South Africa, pp. 591-596, ISSN: 2308-8265
2. **T Bele and TB Tengen (2017),** *Deterioration of commuter rail station efficiency due to varying expectations from commuters and varying rewards for each expectation: a proposed remedy*, in proceedings of 28th Annual SAIIE conference held 25-27 October 2017 at Riverside Sun, Vanderbijlpark, South Africa, paper Ref: 3368, pp 225-236 **– ISBN: 978-1-86822-684-9**
3. **T Bele and TB Tengen (2017),** *The Application of Direct Cluster Algorithm for Improving Train Station Layout*, in proceedings of 28th Annual SAIIE conference held 25-27 October 2017 at Riverside Sun, Vanderbijlpark, South Africa, paper Ref: 3375, pp 289-294 **– ISBN: 978-1-86822-684-9**
4. **T Bele, Benga EBB and TB Tengen (2019),** The Application of Simulated annealing Based Layout Evaluation Algorithm to Redesign a Train station*,* in proceedings of 30th Annual SAIIE conference to be held 30 September -02 October 2019 at Port Elizabeth, South Africa.

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Abbreviations

Direct Cluster Algorithm (DCA)

Norms, Guidelines and Standard for Station Facilities (NGS)

Passenger Railway Agency of South Africa (PRASA)

South African National Standard (SANS)

South African Rail Commuter Corporation (SARCC)

Systematic Layout Procedure (SLP)

Vaal University of Technology (VUT)

CHAPTER ONE

INTRODUCTION, PROBLEM STATEMENT AND RESEARCH (SPECIFIC) OBJECTIVES

1. Introduction:

This dissertation presents findings from a qualitative research study that was conducted at PRASA (Passenger Rail Agency of South Africa). It highlights ways in which a train station can be redesigned to accommodate passengers with special needs. In this introductory chapter, the rationale of the study and an overview of the dissertation is given. The chapter starts off by presenting the background of the initial designs of the South African train stations. A discussion regarding the success of designing train stations that accommodate all passenger types in South Africa is provided i.e. Gautrain. The chapter further articulates the gaps that still exists within the current Mogale City train station. In line with the research methodology and the concept of flexible facility layout a background is given to provide the reader with information that contributed to the initiation of the study. Lastly it then proceeds to explain the objectives of the study.

1.1. Background

In the past, when the commuter rail systems and networks were constructed in Johannesburg, not enough thought was given to take into consideration the many commuter-rail passengers with special needs (Maidin 2012:2). As defined by Webster M (2019), “special needs” means any of various difficulty such as physical, behavioural, learning disability or impairment that causes one to require additional or specialised services or accommodation. The rail industry plays a key role in the future of South Africa and industrialisation as it transports people, goods and services. As parts of a supply chain, it is integral to the economy (PRASA Corporate Plan 2017-2020:12). Currently in South Africa, the commuter train service operates mainly in the urban areas and the services carries approximately 2.1 million passengers daily (Stanburry and Scott 2005:1-2). In the year 2016 to 2017 the service rendered 380 million trips (PRASA Corporate Plan 2017-2020:19) It has also been reported (Papaioannou and Martinez, 2015:1-2) that the expansion of urban areas creates new requirements for transport planners, and that the railway system is perhaps the most efficient way to solve transportation issues in dense urban areas. In the process of planning the urban rail system, elements such as high transportation capacity, fast speed, punctuality, low unit energy consumption, low environment pollution, safety and reliability are important factors that need to be considered carefully.

When one considers the state of South African railway facilities, it's not difficult to see that many constraints and barriers still exists, which mainly affect people with special needs; and some contribute towards the railway safety performance trends (Hutchings J 2017:7). According to South Africa Rail Commuter Corporation (2003), the advantages of improving commuter rail systems include reduction of road accidents, reduction of passenger fatality, reduction of traffic congestion that would have increased costs for road maintenance and have departure and arrival time saving. If one takes into consideration the number of people with disabilities that are in South Africa, then an effort should be made to take cognizance of their problems and acknowledge that people with special needs are not catered for in the railway system (Snyman 2000:24).

In the above light, a lot of research, efforts and resources have been put in place in the Gauteng Province to improve the layout of commuter rail facilities (Ayandibu 2010:2-4), with already examples being the Johannesburg Park Station, Gautrain commuter rail facilities and many to follow. The objective of the Gautrain project is to relieve traffic congestion between Johannesburg and Pretoria and to offer commuters a viable alternative to road transport. As reported by the South African Gautrain Benefits Booster (2010), Gautrain facilities are designed to allow for simple use, flexibility, equitable use, perceptible information management, tolerance for error, low physical effort, effective space utilization and to accommodate for passengers with special needs. These requirements were achieved with the Gautrain system being environmentally friendly, operating in 10 stations, having a length of 80km (50mi), a track gauge of 1,435mm (4ft 8,5 in gauge), electrification of 25kvAC, a top speed of 160km/h (99mph). Also, the its facility layout caters for all passenger types. In this report, some of the facilities and their dimensions required to redesign the Mogale's train station are covered in chapter 4.

Although the Gautrain is the modern solution to the design of commuter rail system that links Johannesburg, Pretoria, Ekhuruleni and O.R International Airport, gaps still exist in that system. It does not serve the townships of Gauteng where transport problem is severe and where the majority of the people live. The situation is even worsened if variables rewards (i.e. rewards mean payments for services rendered) are required to render those services to customers with variables needs in those townships.

To effectively design facilities (such as train stations') layouts, customers' expectations should normally be considered. More often the individuals' specific needs or expectation are not considered since the rule of the majority is mostly applied. Facilities planning techniques learned from industrial engineering may be applied to redesign the layout of a train station (such as the Mogale City's train station) in order for it to be effective and meet its customer's requirements. The redesign of Mogale City's train station borrowed a lot from Johannesburg Train Station in terms of qualities and types of facilities provided, but a redesign proposal (i.e. quantity) was based on the Mogale City specific information. To achieve this, the efficiency of the Johannesburg Train Station was be assessed to see if it could still be improved based on varying customer's expectation.

1.2 Problem statement

The current Mogale City commuter rail facilities' layout doesn't allow for efficient flow of passengers, efficient space utilization and personnel requirements, and as such, this commuter rail layout has to be improved. This inefficient layout is partly due to the fact that it was built in the year 1896 by M.C.A Meischke according to previous South African government building designs regulation, (De Jong *et.al* 1988:95-96). There have been successes that have been recorded at other rail commuter systems whose layout have been improved to accommodate for passengers with special needs (Cloet, C *et.al* 2014:1-10) such as Johannesburg Park Station, Cape Town Train Station, Gautrain, etc. Other Municipalities (with PRASA's train stations) that wish to redesign their existing commuter rail facilities or design new facilities to accommodate passengers with special needs are finding it difficult. The challenge is that this cannot be achieved by a one-to-one transfer of previous model since space, money and information on level of activeness in other facilities are limiting factors since they are not always the same. Therefore, the new localities require their specific information before redesigning their commuter rail facilities. The major issue of this project is how to redesign an existing rail commuter facility at Mogale City to have an effective layout that will consider the specific information from that locality.

1.3 Objective

The main objective of this project is to apply improved facilities planning techniques to redesign the existing commuter rail facility layout in Mogale City to be effective while catering for passengers with special needs.

1.3.1 Specific Objectives

To achieve the major objective, the following specific objectives have to be addressed. An elaboration of how the specific objectives have been achieved and the section(s) where they are addressed are also briefly presented. The specific objectives were

***1.3.1.1. To determine facilities needed to accommodate (or to be provided to) passengers with special needs*:**

The identification of facilities required to redesign train station so that it meets its varying customer's expectations was accomplished by gathering data in the form of interviews, literature survey, reports from train station managers and observations from other successfully redesigned train stations that accommodate passengers with special needs. Some of the facilities that are required are discussed under the implementation section of this report (section 4.6). It was found that it is of importance to implement effective facilities that have assistive devices and technologies for various groups of people. It is also important to ensure compliance with the South African legislation, to improve equal access to services and opportunities including those people with disabilities.

*1.3.1.2. **To determine effective train station layout that include for example***

The entails determining: -

- Personnel/barrier requirements such as restaurants, rest rooms, special need equipment

  This was achieved through literature survey and interview

- Space requirement

  This was achieved by establishing the Block Diagram (dealt with in section 4.3) and also employing Direct Cluster Algorithm (DCA) (dealt with in section 4.4)

- Effective Commuter Flow

  This was achieved by the application of the From-To-Chart Technique (found in (section 4.3)

- Spatial Placement of needed facilities i.e. location of one facility with respect to the next one.

  This was achieved by establishing block diagrams (see Diagram 1 and 2 of section 4.3).

1.3.1.3. To select the effective facility layout for different peak periods.

Different peak periods pose the challenge of generating different efficiencies if their individual information is used to propose the layout of the train station. As such Simulated Annealing was used to combine various scenarios, compute and then compare the different peak period layouts' efficiencies so as to decide on the one that best suits the overall expectation. This is covered under section 4.5.

1.3.1.4. To implement and test to validate the effectiveness of the system.

This was achieved by presenting and discussing the results with the train station managers. This was done to find out if they have tried any of the approaches to solve the issues in the train station, by providing facilities to accommodate for different passenger types and re-arranging departments to improve passenger flow. (This is found in the implementation section 4.6-4.7 or PART 4B).

1.4. Concluding Remarks

The outline of this reports is as follows. It starts off with the introduction of the study which is found in chapter one the problem statement and specific objectives are also covered in chapter one.

A background of the study and Mogale city train station is presented in chapter two. This is followed by literature review in chapter two. The literature review covers what others have done internationally on the subject of facility planning, other researchers works are discussed and it further articulates the gaps that still exists in the Mogale City train station.

Chapter three introduces the facility planning techniques employed in order to have effective trains station layout. This chapter covers the research process on how to develop alternatives facility plans.

Chapter four is divided into two major parts. PART 4A that deals with searching whether further improvement can be made the already upgraded train station at Johannesburg (I.e. at Johannesburg Park Station). PART 4B presents facilities that can be upgraded at the Mogale City Train Station and how to redesign the new layout.

Chapter five concludes the study by presenting a summary of the overall research, stating the limitations of the research and providing recommendations for future research.

<u>CHAPTER TWO</u>

2.LITERATURE REVIEW

2.1 Background

This chapter presents a deeper search into the literature so as to have further and deeper understanding of the issue at hand to be addressed. This starts with background to the development and the need for expansion or redesign of the train station at the Mogale City. The is followed by the guidelines or principles for universal design. Some of the know-how that should be considered to have an effective facility layout design is also covered. And finally, the importance of upgrading the Mogale City train station is discussed.

The first railway system in South Africa was developed in the 1850s by private enterprises (Johnson I 2012:11). In 1867 after the discovery of diamonds, Kimberly became the catalyst of railway system. At about the same time when Kimberly railway system was developed, gold deposits were discovered in Gauteng. When gold was discovered in 1886, there was no industrial infrastructure in the West Rand area (De Jong *et.al* 2015). It then became clear that transport wagons could not meet the demands made by the growing mining camps and increasing number of mines, which needed heavy construction material and coal. Due to the discovery of gold on the West Rand and coal on the East Rand, there was the need for a transport link between the two areas. This led to construction of the Krugersdorp station. A light railway building with the rail was then developed and the dimension of the railway was according to the South African Railway Gauge Standard which is 1065mm (3 feet 6 inch) (De Jong *et.al* 2015), shown below in figure 1. The building was a standard corrugated iron structure with a curved roof and veranda. The construction of the building started in July 1895 and ended in 1896. The design of the train station was according to Nederlandsche Zuid-Afrikaansche Spoorweg-Maatscheppj (NZASM), which was the previous South African government standard (see figure 1 for the outside view of the building).

The first passenger commuter train to operate in Gauteng was introduced in the year 1890 (Johnson I, 2012:11). Railways lines in other provinces were later opened and by 1898 a national link-up was established thereby creating a national network. Industrialization and commercial developments in and around cities presented many job opportunities, which attracted a lot of people. This vast urbanization stimulated the need for more efficient rail passenger services.

The original purpose of the train station has changed due to the growing market and globalizations, where customer demands are changing continuously, and where enterprises need to focus on cost reductions and profitability (Korvacs *et. al* 2017: 1).

Fig 1: *Krugersdorp Train station*

2.2 Location

The train station discussed in this project is located at Mogale City previously known as Krugersdorp Local Council (see Fig 1). It is situated at the western side of Gauteng. The city covers an area of approximately 110 000 hectares. It accessible from all major centres of Gauteng and North West provinces namely Johannesburg, Pretoria, Midrand and Haartebeesport Dam, Randfontein and Soweto.

Mogale City has a mixture of urban and rural areas. The urban area is due to different levels of development and a concentration of informal settlements with little free space available. This city is in an economic hub of South Africa, with its train station close to the national highway N14 and Lanseria International Airport. There are major attractions around such as Maropeng, Sterkfontein caves and Silver Star Casino. The expansion of the city and the need to expand the train station create an opportunity to achieve service delivery agenda i.e. business opportunities around the train station.

Following the need to expand the Mogale City's Train Station, it is obvious that some design and redesign works have to be done. Thus, it is vital to present some information on these design and redesign processes, which are found below.

2.3 The Principles of Universal Design

The Centre for Universal Design conducted a research and came up with the need to set universal design guidelines (project no H133A40006), called Principle of Universal Design Guidelines (Connel B *et.al* 1997, Steinfeld and Maisel 2010). The purpose of the Principles of Universal Design and their associated guidelines is to ensure that the concepts of universal design principles are applied to all design disciplines including those that focus on built environments, products and communication. The principles are intended to guide the design process, allow for systematic evaluation of designs and assist in educating both designers and consumers about characteristics of more usable design solution (Story *et.al* 1998). The authors of universal principles investigated the conceptual principles, design guidelines, design strategies and tests for compliance. The Principles of Universal Design, listed below (Connell *et.al* 1997);

Principle 1: ***Equitable use*** – it states that the design should appeal to diverse population and should offer everyone a comparable non-stigmatizing way to participate. It should be useful and marketable to people with diverse abilities. This implies that same benefit for all users, which is identical and equivalent. Segregation or stigmatizing of any users should be avoided. Provision for privacy, security and safety should be equally available to all users. In broad the design should be appealing to all users.

Principle 2: ***Flexibility in use*** – it states that designs should accommodate a wide range of individual preferences and abilities. The design should provide for multiple ways of doing things, with adaptability being key to make the design universally operational. This implies that provision of choice in methods of use should be given. For instance, accommodation for right-handed or left-handed access and use should be included. Facilitation of the user's accuracy and precision should be granted and provide adaptability to the user's pace.

Principle 3: ***Simple and Intuitive use*** – it states that the design should be easy to understand, regardless of the user's experience, knowledge, language, skills or current concentration level. This means that unnecessary complexities should be eliminated. Consistency with the user's expectations and intuition should be primary. A wide range of literacy and language skills should be accommodated for and it's also vital to arrange information consistency according to its importance. Provision should be given to effectively prompt and feedback during and after task completion.

Principle 4: ***Perceptible Information*** – it states that the design should communicate necessary information to the user, regardless of ambient conditions or user's sensory abilities. The use of different modes such as pictorial, verbal or tactile for presentation of information is strongly recommended. The design should provide adequate contrast between essential information and its surroundings. Legibility of essential information should be maximized. Elements should be differentiated in ways that can be described i.e. making it easy to give instruction or directions. Importantly also is to give provision of compatibility with a variety of techniques or devices used by people with sensory limitations.

Principle 5: ***Tolerance for Error*** – it states that the design should minimize hazards and the adverse consequences of accidental or unintended actions. The design should make it difficult for users to make mistakes but if the users do, the error should not result in injury to the person or damage to the product. This involves arranging elements to minimize hazards and errors by making the most used elements accessible and hazardous elements eliminated or isolated. Warnings of hazards or errors should be provided and unconscious action in tasks that require vigilance should be discouraged.

Principle 6: ***Low Physical Effort*** – it states that the design should be used efficiently, comfortably and with minimum fatigue. In other words, the design should minimize strain and over exertion. This can be achieved by allowing users to maintain a neutral body position and use reasonable operating forces.

Principle 7: ***Size and space to approach and use*** – it states that appropriate size and space should be provided for reach, manipulation and use regardless of the user's body size, posture or mobility. This implies that, the design should accommodate variety of people's sizes and ranges of motion. This can be accomplished by providing a clear line of sight to important elements for any seated or standing user. Variations in hand and grip size should be accommodated and adequate provision of space should be given for the use of assistive devices or personal assistance.Facilities layout should be able to provide an ideal relationship between passenger and equipment at minimal cost. This should be achieved under safe and comfortable environment.

The next section covers some of the know-how that should be considered to have an effective facility layout design.

2.4 Design of Facilities Layout

The principles that drive the design of a facilities layout should take into consideration the objective of the facilities layout, factors influencing the facilities layout and constraints of the facilities layout. These principles are:

1.3.1 **Flexibility:** Facilities layout should provide flexibility for expansion or modification.

1.3.2 **Space Utilization:** Optimum space utilization reduces the time of material and people movement and promotes safety.

1.3.3 **Capital:** Capital investment should be minimal when finalizing different models of facilities layout.

The next section discusses the importance of upgrading Mogale City train station.

2.5. Upgrade of the Mogale City's Train Station

In the new world of connectivity, where systems rather than small fixes are embraced by facilities layout planners as well as policy makers, it is meaningful to integrate all aspects of sustainable, social, economic and environmental impacts in order to improve the commuter rail system. The passenger rail of South Africa (2015) reported that the

Mogale City's train station has to be modernized. The upgrade included improvements in the processing departments and physical display or layout, provision of new tracks, closed-circuit television, cameras, improved lighting, better signage, as well as improvements to the aesthetics. Vavi, I (2014) reported to the Mogale City's train station managers that the train station's copper cable signalling system that is prone to theft must be upgraded at a cost of R1 billion. Wolfgang, F *et.al* (2001: 1-24) stated that the world has experienced a transformation through social, technological, economic, environmental and legal changes that have altered both the philosophical discourses and the physical practices of design at all scales. To proceed, it is important to borrow from other success from around the world, as elaborated below, to try to address the current problem.

In 2008 the United States Green Building Council and the American Institute of Architects organized two major conferences aimed at exploring solutions and means of designing effective facilities (Szencysy S, 2008 2:45-46). In his keynote address, South African Archbishop Desmond TuTu (2008) described the economic and social reality of the global connected age by stating that "There's enough in our world for everyone's need but not enough for everyone's greed". He continued to remind the audience that if structures are built to be friendly to the people and to the environment, then we will achieve what he called a Global Sustainable Village (Greenbuild, 2008). The chairman of the conference, Farr, D (2008), reported that is it inevitable that two most powerful design trends of our time are sustainability and universal access, which led to the program to devote a credit to universal accessibility (Meyers 2007). Hawkens, P (2008) described the importance of design skills, understanding and giving all people equal opportunity in public service delivery as system.

Furthermore, a lot of research has been conducted to address the issue of universal access by improving the design of public building and facilities. This includes an approach that was taken by Kemp, J (2002:1,38) where designers with disabilities were invited to participate in the planning and designing of various facilities so as to understand their personal experiences of having (i.e. with) disability. This was seen as way to accommodate diversity and possibly educate non-disabled designers to be able to plan facilities that will cater for the needs of all persons. Rawsthorn, A (2008) added that this type of facilities planners should have skills to analyse complex design systems from new perspective. This broadened approach should start in lower levels of schooling, from urban to rural settings and from less developed to more developed economics. Passenger Rail system decision makers, municipalities and state should also have a grounded experience in design as a tool to improve services offered to the diverse needs of customers.

It is important to take note that all persons who use a mass transportation system should stand to benefit from universal access (Steinfeld, E 2008:19:200). Thus, everyone should share ideas during the investment not just people with disabilities. In today's global economy, a convenience, safe and effective mass transport system is essential aspect of social sustainability. Traditionally, train stations should break large terminals into small ones so as to reduce travel distance within terminals which can be a barrier for passengers. While many lessons have been learned in the design of accessible trains stations, there's still concerns that are not addressed by existing guidelines and standards such as flexible layout planning.

The Passenger Rail Agency of South Africa launched a project from which the need of integrating universally accessible designs into their projects was identified. This implies that South African rail commuter rail systems should give equal opportunity and accessibility to services, products, systems and environments regardless of economic situations, social situation, religious or cultural background, gender and functional limitations. Thus, characteristics such as political settings, scheduling, in-house expertise of authorities, co-ordination between land and transport policies have to be considered. Maidin, A (2012) reported that focusing on a friendly commuter rail facility design would create a friendly atmosphere for public transport use. However, Baanders and Delahais (2014) researched and found out that complying with government standards requires a high cost to meet the quality of services that are supposed to be offered to accommodate rail passengers.

As such, researchers started looking for various methods that will solve the issue of accommodating various passengers in train stations. Kantawong, A (2011) found wheelchair ramp lift boarding-support system for public transport that should be used by wheelchair passengers. This was not enough, as the solution only focused on passengers on wheelchairs. Then Huaizhang Zhu *et.al (*2018) determined a method that will predict passenger flow (e.g. scenario planning and forecasting) in order to allocate necessary resources to improve travel requirements for citizens. Van der Merwe, J (2011) studied passenger behaviour in Gauteng Province and identified various socio-demographics attributes that can affect individuals travel behaviours. The study successfully expanded day-to-day travel experience and included non-work activities.

Congestion was also identified in commuter rail facilities, which was a result of poor facilities planning (Starmans *et.al* 2014). The research by Starmans *et.al* (2014) suggested that by applying the macroscopic passenger model approach to redesigning facilities, the evaluation of train positions, train schedules and commuter rail facilities platform can be achieved. From their work on commuter rail platform, they suggested that a vertical infrastructure could be implemented, which would increase capacity, increase space and decrease queues. The model also suggested that the vertical structure would increase the highly needed outer escalators and stairs, which would improve on passenger flow. However, this approach doesn't cater for all passenger types, e.g. the disabled will not be catered for in this type of layout.

An approach of modelling and simulation (e.g. simulated annealing), which plays a vital role in modern life (Pace, D 2004) as it mimics the behaviours of the real systems and it is essential in the effective design, evaluation and operation of new systems, was explored by other authors. The first simulated annealing was performed by Kirkpatrick *et.al* (1983). Simulated Annealing is a stochastic optimization technique (such as Monte Carlo Simulation) used to solve challenging combinatorial optimization problems (Barretto *et.al* 1998). Simulated Annealing is derived from analogy to determine the behaviour of a physical system by melting a substance and lowering its temperature slowly until it reaches a freezing point. The slow cooling implemented in the simulated annealing algorithm is interpreted as a slow decrease in the probability of accepting worse solutions as the solution space is explored. In metaheuristics, accepting worst solutions is a fundamental property as it allows more extensive search for the global optimum solution.

As reported by Al-Khedhairi, A (2008), simulated annealing can be described as follows: for each an optimization problem, there's a set of feasible solutions with each solution *S* having a cost value obtained from the cost function *f(s).* The objective is to find a feasible solution with a minimum cost. Local optimum is identified by finding the cost of an initial solution S generated from an initial combination of conditions or parameters and then repeatedly attempting to find a better solution by moving to a neighbouring set of conditions with a lower cost function.

Momeni *et. al* (2012) investigated that it is possible to save significant time and cost if facilities layout challenges are solved and, furthermore, by also using simulated annealing to develop an efficient layout in a railways system. In this project the concept of simulation annealing was applied on the From-to-Chart technique, which is the optimisation (or cost) function for determining effective flow pattern. The cost (i.e. efficiency in this particular case) of the current layout obtained from the overall data of the all peak periods was obtained. The solution or cost of the other set of conditions (different peak period) was determined and a decision to move or stay with current solution was based on the efficiency obtained when compared with the efficiency obtained using overall data. Peak hours, passenger volumes, location of facilities and passengers' flow routes through these facilities were used as the control parameters to determine the cost of the flow pattern

The next thing to do is how the redesign of the Mogale City Train station was approached. This redesign of Mogale city train station was borrowed from Johannesburg Train Station in terms of qualities and facilities provided, but a redesign quantity or magnitude or proposal was made based on the Mogale City specific information. In this regard, the efficiency of the Johannesburg Train Station was assessed to see if it could still be improved based on varying customer's expectation.

The next chapter covers this concept.

CHAPTER THREE

3. METHODOLOGY

3.1 INTRODUCTION

As indicated in the preceding chapters facilities planning techniques were applied to study the current train station layout and to propose a new effective layout for Mogale City train station by borrowing layout designs from Johannesburg Park station.

3.2 Research Design

This was a quantitative study, which made use of facility planning techniques to assist in gathering relevant data. Quantities research was used because it is a systematic investigation of phenomena by gathering quantifiable data and performing statistical, mathematical or computational technique. Information was collected from the existing and potential rail passengers through sampling method, direct observations and questionnaires. The results were depicted (see section 4.5) in the form of numerical to predict future services, passenger volumes and to make changes accordingly.

3.3 Determining facilities that Cater for Passengers with special needs

To determine the facilities that should accommodate passengers with special needs, fieldwork was conducted through the use of:

Database - Part of the information on types of facilities that should be provided to cater for passengers with special needs was sourced from available database, which included journals, previous research findings and commuter rail facilities management reports.

Interviews - commuter rail passengers and personnel were interviewed to obtain information on their specific needs and requirements

Observations - The passengers' behaviour was observed and the level of activeness of people in the commuter rail facilities was obtained so as to know the level of demand.

Statutory Bodies - The South African National standards and regulations for buildings regarding persons with special needs were consulted to ensure the compliance of identified facilities.

3.4 Muther's systematic layout planning procedure

The case study Company was Passenger Rail Agency of South Africa (PRASA) at Mogale City. Information at Johannesburg Park Station was also used as this train station is already established so as to find out if it can still be improved. Tompkins *et.al* (2010:6, 296-302) pointed out that if information that can assist to improve on existing layout or that can be used to develop alternative layouts is obtained then, the Muther's Systematically Layout Planning Procedure can be followed. A systematic layout procedure (SLP) is a design approach which was developed by Muther in the year 1961. Researchers such as Keraita J *et.al* (2018) conducted a casestudy using the SLP method to improve an existing layout for increased productivity and space utilisation. This study was done due to need for a flexible layout that allows effective space utilization and flow of passengers. The method showed that an activity chart was formed, studied and new layout alternatives were developed. The Muther's Systematic Layout Planning Procedure was used to systematically establish an effective block diagram of the physical layout or display of each department based on the data that was collected. This procedure uses activity relationship chart as its foundation (Tompkins 2003), activities performed based on the input data such as the type of passengers, quantity, route, support, time and knowledge of the roles and relationship between activities. The input data helps generate a passenger flow analysis chart which is referred to as From-To-Chart. This was achieved by employing the following sub-techniques that ensure that some of the key elements of the layout are also effectives. The From-To-Chart approach technique was used to measure the effectiveness of sequences of flow, intensity of flow and the amount of backtracking. From the outcomes of the From-To-Chart evaluation, an improved flow pattern or route to be followed by passengers at the train station was proposed by minimising backtracking. This backtracking was specifically minimised by letting departments with high-penalty-points (that indicated high level of backtracking) to be placed closer to each other. After having determined the efficiencies of the current layout and that of the improved layout, it was then important to verify if the current data could produce a physical display or layout of the departments at the train station similar to the current practical display, and to propose a new layout using the improved flow pattern. The technique of activity relationship charts was used to obtain information on effective flow activity, from which the block diagrams were established. In summary, the From-To-Chart technique was employed to quantify the efficiency of passengers' route (i.e. where departments are placed with respect to each other), followed by the application of the activity relationship chart techniques and then the establishment of the physical display through block diagram techniques. A little details on how these were achieved is given below.

In order to apply the From-To-Chart technique, all processes or departments servicing passengers were listed in the order that was identical to the required flow route across the column (on top of the chart) and down the row (on the left hand side of the chart). The listing was in the direction of the overall average flow pattern from entrance to exit. The next thing that was required was a compilation of process sequence for a group of representative passengers using information from process chart. In general, this may have to include flow volume, distances travelled, costs etc. The effort required by passengers and also to assist passengers (i.e. flow efficiency) was achieved by performing the From-To-Chat analysis for each data set.

The steps involved in employing the Muther's Systematic Layout Planning procedure that was employed in this report is summarised below. This involved: (Tompkins *et.al* 2010 6, 297-302).

3.4.1 Information about the passengers with special needs was obtained and the data recorded systematically.

3.4.2 Data on the travelled distance, passenger quantity, and cost per kilometre for each type of passenger was collected.

3.4.3 The From-To-Chart was applied on the distance, quantity of passengers and cost per kilometre for each type of passenger so as to determine the efficiencies of the routes.

3.4.4 Subsequently, the flow between departments was established using the flow-between-chart technique

3.4.5 The flow-between values were ranked from the flow-between-chart in descending order of magnitude so as to establish the activity charts.

3.4.6 The relationship diagrams were constructed from the information obtained from the activity charts.

3.4.7 The block diagrams were then established so as to visualize how the layout of the station (i.e. the physical display of the departments) should look like for effective flow.

3.5 Direct Cluster Algorithm

Other techniques exist that could be used to propose the layouts of the train stations by grouping facilities that perform similar services to form (i.e. to belong to) common cells. An approach of grouping facilities to form cells that was also tested was the Direct Clustering Algorithm.

The Direct Cluster Algorithm (DCA) was applied to combine departments performing services to passengers to form cells so as to reduce the cost of movement and minimize “conflicts” within train stations (Maidin, A 2012). Chan and Miller (1986) stated that clustering methodologies could be used to group parts (or in this case, passengers) together so that they can be processed as a family in a cell. Singh and Rajamani (1996) presented a wide range of algorithms for forming cells. Among those considered were Bond Energy Algorithm (BEA), Rank Order Clustering (ROC and ROC 2), Modified Rank Order Clustering (MODROC), Direct Clustering Algorithm (DCA), Cluster Identification Algorithm (CIA), Single Linkage Clustering (SLC) and Linear Clustering Algorithms (LCA). These algorithms use mathematical programming approaches, including formulating cells problems as a *p*-median covering problem, an assigned problem, a quadratic assignment problem and a non-linear optimization problem. In addition clustering can improve management of efficiencies by having a better understanding of different travel periods, travel patterns, travel characteristics related to temporal and spatial variability (Huiyi C *et.al* 2017)

In this project the DCA was used which is based on machine-part matrix (department-passenger matrix) where in the matrix a 1 indicates that the passenger was served at that particular department and a blank indicates that the department was not used to assist the particular passenger. Borrowing from Tompkins *et.al* (2010:3,102-103), the Direct Cluster Algorithm was achieved by by the following steps;

3.5.1 Completing the Machine-Part Matrix (specifically the service department –

passenger matrix in our particular case). Assigning 1s and blanks, as explained above, into an initial matrix, led to this machine-part matrix.

3.5.2 ***Ordering the rows and columns.*** The 1s in each column and each row of the department-passenger matrix were summed. This was followed by ordering the rows (top to bottom) in descending order of the number of 1s in the rows and ordering the columns (left to right) in ascending order of the number of 1s in each. Where ties existed, the ties were broken in descending numerical sequence.

3.5.3 ***Sorting the columns.*** Beginning with the first row of the matrix, all columns having a 1 in the first row were shifted to the left of the matrix. The process was continued, row-by-row, until no further opportunity existed for shifting columns.

3.5.4 ***Sorting the rows.*** Column by column, beginning with the leftmost column, rows were shifted upwards and when opportunities existed blocks of 1s were formed.

3.5.5 ***Forming cells.*** Opportunities were searched to form cells such that all processing for each passenger occurs in a single cell or in cells closer to each other.

After presenting an approach to determining the effective route using From-To-Chart technique, the formation of the physical layout using Block Diagram technique and also an approach of combining departments into cells using the DCA, it is important to note that their outputs may vary depending on the data set, such as the different peak periods. Thus, a further approach (i.e. simulated annealing) that handles different peak periods to establish which peak periods can be used to design the train station has to be presented next.

3.6 Simulated Annealing

Simulated Annealing is a method based on Monte Carlo Simulation to solve challenging combinatorial optimization problems (Barreto. P *et.al* 1998). The first simulated annealing was performed by Kirkpatrick et.al (1983). It is a stochastic optimization technique. Simulated Annealing is derived from analogy to determine the behaviour of a physical system by melting a substance and lowering its temperature slowly until it reaches a freezing point. The slow cooling implemented in the simulated annealing algorithm is interpreted as a slow decrease in the probability of accepting worse solutions as the solution space is explored. In metaheuristics, accepting worst solutions is a fundamental property as it allows more extensive search for the global optimum solution

Simulated annealing can be achieved as follows: for each optimization problem there's a set of feasible solutions with each solution S having a cost value obtained from the cost function f(s) (Al-Khedhairi, A 2008). The objective is to find a feasible solution with a minimum cost. Local optimum is found by finding the cost of an initial solution S generated from an initial combination of conditions or parameters; and then repeatedly attempting to find a better solution by moving to a neighbouring set of conditions with a lower cost function.

It is possible to save significant time and cost if facilities layout challenges are solved and, furthermore, by also using simulated annealing to develop an efficient layout in a railways system (Momei, M et.al 2012). In this project the concept of simulated annealing was applied on the From-To-Chart technique, which is the optimization (or cost) function for determining effective flow pattern. The cost (i.e. efficiency in our particular case) of the current layout obtained from the overall data of the all peak periods was obtained. The solution or cost of the next set of conditions for the different peak period was then obtained and a decision to move or stay with current solution was based on the efficiency obtained when compared with the overall efficiency. Peak hours, passenger volumes, location of facilities and passengers' flow routes to these facilities were used as the control parameters to determine the cost of the flow pattern, with the intention of finding the route or flow pattern whose total cost was minimal or finding highly effective layout or route.

It should be recalled that it has been presented that the From-To-Chart technique was used to determine efficiencies of the routes and improve on them by minimizing backtracking. The Block Diagram strategy was subsequently used to propose the physical display of the improved train station layout. The issue that arose was the fact that the commuter rail system experienced different peak periods with different volumes that summed up to the overall data. When different peak periods and their associated volumes were used to design the train station layout, then the flow patterns from the different peak periods had different efficiencies under the different conditions.

So, the skill of simulated annealing was used on the different peak periods so as to determine an effective facilities layout that will accommodate for passengers with special needs at all times. As the fundamental concept of simulated annealing comes from statistical mechanics and combinatorial optimization (Tompkins et.al 2010), the optimal layout was constrained by identifying how the different passenger types use the train station (i.e. their pattern of use) so as to effectively combine the different volumes or numbers. The pattern that was identified was that passengers of specific types mostly used the train station during the specific peak periods that were more convenient to them; either to go to work/schools or to get better assistance.

CHAPTER FOUR

4. COLLECTED DATA, ANALYSIS, RESULTS AND IMPLEMENTATION

4.1 Background

This chapter is made up of two parts. The first part deals with data that was obtained at an established Train Station (which is Johannesburg Park Station) and the analysis that was done to find if improvement (i.e. continuous improvement) can still be done at such an improved train station. The improvement modalities were discussed with the station manager to see if they will buy the ideas or whether they had ever thought of trying them. This was done in the spirit that it is difficult to start re-arranging the layout of the train station from just a single study. In line with this last statement, the second part of the chapter deals with data obtained from Mogale City (Train Station) with the analysis that was done to find out how the improved train station layout should look like. The improved Mogale City Train Station’s layout was presented to the city/station manager for consideration. The discussion with the Mogale City station manager also included some of the selected facilities (with their dimensions and requirements) that can be provided at Mogale city station (which is covered under implementation section).

PART 4 A

4.2 Data Collection

Data was collected through the use of primary and secondary sources. The primary sources included visits to the existing commuter rail stations in Johannesburg and Mogale City to observe passenger behaviour, passenger flow, current facilities which are medical centre, retail, ticket sales area, ablution facilities and offices. A survey is the most fundamental tool for all quantitative research methodologies and studies (Question Pro.com). A survey was used to ask questions to a sample of different passenger types whom were observed and identified at the train station. This was done to understand what various rail passenger think of the services that they are offered and how PRASA can improve, to offer better services to their passengers. Further information was obtained through interviews with the head offices of the Passenger Rail Agency in South Africa, to establish guidelines and restrictions, which informed the design of a train station.

The secondary sources of information were from literature, journals, textbooks, Internet sources, conferences proceedings and reports that are relevant to this dissertation. The information attained through this method included history of the Mogale City trains station, benefits of redesigning train stations and types of facilities that could be provided at train stations to cater for passengers with special needs inclusive.

Table 1: *Description of passenger with special needs observed at the train station and how they are identified*

Passenger Type	Description	Method used to Identify
Children	People under the age of 12	Informed by train station
Elderly	People at the age of 60 and above	Informed by train station
Physically Limited	Physically defective e.g. People	Direct Observation
Auditory Limited	Half Deaf, Deaf, Defective speech	Informed by train station
Inebriated Limited	Defective motion and speech	Direct observation
Cognitive Limited	Mentally Defective and speech	Direct observation
Linguistic Limited	Foreigners who don't understand	Direct observation
Pregnant women	Protruded stomach	Direct observation
Temporary limited	Restricted daily activities e.g.	Direct observation
Visually Limited	Defective eyesight and use of	Direct observations
Paraplegic	Use of wheelchairs	Direct Observations

Table 1 describes the different types of passengers with special needs and also gives information on how to identify them at the train station. The types of passengers with special needs are children, the elderly, physically limited, auditory limited, inebriated limited, cognitive limited, linguistic limited, pregnant women, temporary limited, visually limited and paraplegics (people on wheelchairs) as found out from other research by Swart P (2016).

4.3. FROM-TO-CHART, ACTIVITY RELATIONSHIP CHART and BLOCK DIAGRAM

4.3.1 Assumptions and Constraints used in the analyses

The following sets of assumptions and constraints were made so as to guide the data collection and analyses process:

4.3.1.1Changing to the new proposed layout should not affect significantly normal passenger and other people employed to work at the train station facilities i.e. PRASA Employees

4.3.1.2 This research only deals with the route from the taxi transit area into the train station entrance: to new retail departments, the shosholoza premier class, continuing to the medical centre and finally the exit into the train.

4.3.1.3 The cost per person was determined by dividing the total cost of facilities and direct rewards by the number of use before replacement or maintenance.

4.3.1.4 Only a sample of 3422 passengers was used to determine the type of passengers requiring special attention.

4.3.1.5 Two scenarios were considered; first scenario where cost per passenger was not taken into consideration and a second scenario where cost per passenger (identifying various needs) was considered.

Figure 2 is a schematic representation of the Johannesburg Train (or Park) Station. The major different departments can be observed and are differentiated by the different colours of the blocks. These departments are “entrance to the taxi rank”, “ablutions which cater for normal passengers and the disabled passengers”, “retail (Game shopping store)”, “business lounges”, “Shosholoza premier classes”, “medical centre” and “train station exit platform on which passenger catch trains to various destinations”. For simplicity of analysis, these departments shall be represented by the symbols A, B, C, D, E, F and G.

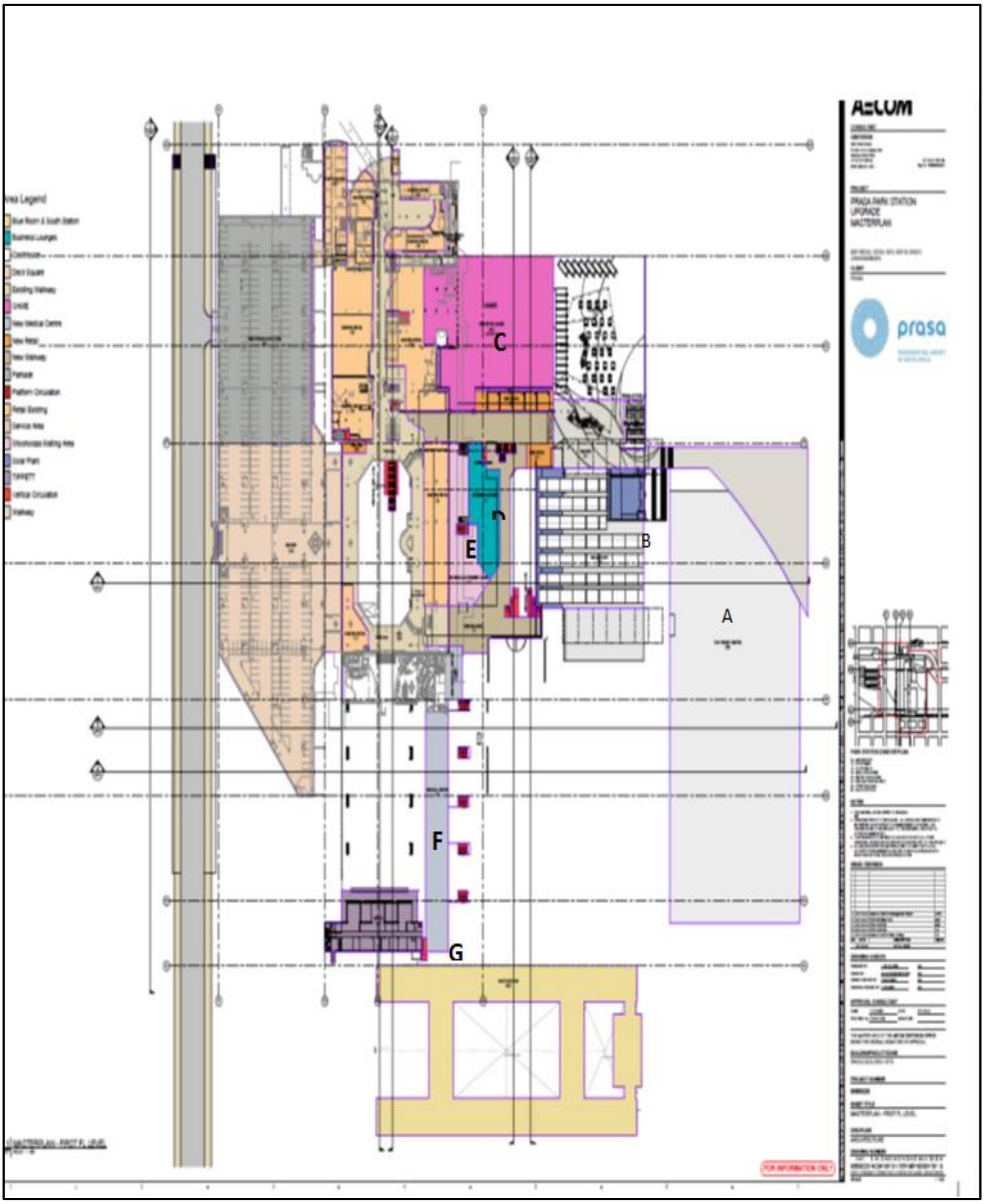


Fig 2: *Layout of the Johannesburg Park Station (Kwesiga.M 2017)*

The flow in this Park Station was used to benchmark the Mogale's City Train Station, to see if improvement can still be achieved at the Park station. This should give more backing or substance to the proposal made for Mogale's City train station for improvement.

To test the possibility for improvement, two major scenarios were tested. This included a situation where only "number of passengers" and "distance" can be used to redesign the Park Station train station layout; and another situation where this redesign process can be achieved by using only "number of passengers", "distance" and "rewards for rendering services to these passengers".

The movement of these passengers was observed from the taxi rank through the train station with a travel route labelled as follows;

A. ***entrance to the taxi rank,***

B. ***ablutions which cater for normal passengers and the disabled passengers,***

C. ***retail (Game shopping store),***

D. ***business lounges,***

E. ***Shosholoza premier classes,***

F. ***medical centre and***

G. ***train station exit platform on which passenger catch trains to various destinations.***

SCENARIO 4.3.2: (First Scenario) Layout obtained from number of passengers and distance of travel

To obtain the layout of this scenario, the cost was not taken into consideration. Table 2 below gives information on various passengers and their different routes in the train station.

Table 2: *Passengers with special needs information*

	ROUTE	QUANTITY	DISTANC	TOTAL	RELATIVE
CHILDREN	A-B-C-F-G	300	1.5	450	2.25
ELDERLY	A-B-C-F-D-G	500	4	2000	10
PHYISICAL LIMITED	A-F-D-G	480	1.5	720	3.6
COGNITIVELIMITED	A-B-C-F-G	350	3.5	1225	6.125
LINGUISTIC LIMITED	A-C-E-G	200	1	200	1
AUDITORY LIMITED	A-B-C-F-G	100	2.5	250	1.25
VISUALLY LIMITED	A-F-E-D-G	150	2.5	375	1.875
TEMPORARY LIMITED	A-C-D-F-G	189	3	567	2.835
PREGNANT	A-B-C-E-F-D-G	488	9.6	4684.8	23.424
INEBRIATEDPERSON	A-B-E-G	400	1	400	2
WHEELCHAIR	A-B-C-E-G	265	3.5	927.5	4.6375

Table 3 below shows the from-To-Chart calculation for the average route ABCDEFG (i.e. a greater majority of the commuters are expected to enter the train station from the taxi rank at A, and then move to B which are ablutions that cater for normal passengers and the disabled passengers, then to C (Game shopping store), then to D (i.e. business lounges), then to E (Shosholoza premier class), then to F (medical centre) and then to G which is the exit to train station platform from where passengers catch trains to various destinations) i.e. the average route that passengers have to follow in the train station. We had to calculate the efficiency of the prescribed or average routed using From-To-Chart techniques, which involves finding the relative distance values (Table 2), entering these relative distance values into the corresponding “penalty point entries” and “total point entries” on the From-To-Chart based on the routes taken by each passenger type (see first-eight column of Table 3), and the summing these entries to obtain the total point and penalty point. In table 3 and subsequent ones, the entries in black colours are used to calculate (i.e. by summing up to obtain) the Total Points and the entries in red are similarly used to obtain the Penalty Point. These Total Points and Penalty Points are then summed to calculate the efficiency of the prescribed flow pattern.

Table 3: *Current layout and flow pattern From-To-Chart for scenario one*

	A	B	C	D	E	F	G	Total point	Penalty Point
A	XXX	115.3: 115.3	6.1: 12.2	0	0	7.2: 36	0	128.6	163.5
B	0	XXX	108.1: 108.1	0	9.8: 29.4	0	0	117.8	137.5
C	0	0	XXX	3.6: 3.6	69.7: 139.4	38.4: 115.2	0	111.6	257,8
D	0	0	0	XXX	0	3.6: 7.2	71.2: 213.6	74.7	220.8
E	0	0	0	0	XXX	46.9: 46.9	40.7: 81.4	86.7	128.3
F	0	0	0	25.2: 100.8	7.2: 14.4	XXX	16.7: 16.7	49.1	131.9
G	0	0	0	0	0	0	XXX	0	0
							SUM	568.6	1039.8

This gives the efficiency of this prescribed flow pattern under *scenario 1* as (sum of Total point) divided by (sum of penalty point) = 568.6/1039.8= 55%

An efficiency of 55% for prescribed flow pattern is not good enough. So, a revised flow pattern or route has to be proposed. According to the knowledge enshrined in From-To-Chart Technique, those departments with high Penalty entries (which signifies high impact of back tracking) have to be placed closer to each other. Upon applying this principle, the newly proposed average flow pattern or route or layout from this project should be ABDECFG. This improved average routing should thus indicate how the various departments should be placed with respect to each other.

Using the proposed new routing of ABDECFG, the principle of From-To-Chart was applied again to determine its efficiency. The results in Table 4 below were obtained. It should be noticed that the efficiency of the proposed average layout or route shows significant improvement from 55% to 75%. This indicates a service delivery satisfaction improvement from 56% to 75%. Thus, there exists enormous potential to improve on service delivery by employing the From-To-Chart techniques when service has to be rendered to individuals who have to move from department to another.

Table 4: *Improved layout From-to-chart for scenario one*

	A	B	D	E	C	F	G	Total point	Penalty Point
A	xxx	115.3: 115.3	6.1: 12.2	0	17.6: 70.4	0	0	139.0	197.9
B	0	xxx	108.1: 108.1	7.2: 19.4	0	0	0	115.3	122.5
D	0	0	xxx	72.2: 72.2	38.3: 76.6	3.6: 10.8	0	114.1	159,6
E	0	0	0	xxx	46: 46	7.2: 14.4	33.5: 100,5	86.7	160,94
C	0	0	0	7.2: 14.4	xxx	81.6: 81.6	16.7: 33,4	105.5	129,4
F	0	0	0	0	3.6: 7.2	xxx	89: 89	92.4	103.4
G	0	0	0	0	0	0	xxx	0	0
							SUM	653.1	873.74

Upon completion of the From-To-Chart the efficiency of current layout scenario one is 653.1/873.74= 75%.

SCENARIO 4.3.3: (Second Scenario) Layout obtained from number of passengers, distance travelled and cost per distance

Under this scenario both distance travelled and cost incurred to facilitate commuters to travel those distances within the commuter train station were considered. It is obvious that commuters with different needs will require different amount of care, which translates into variable costs considered under this scenario, where the obtained data is presented in Table 5.

Table 5: *Information on passenger's with special needs with cost values*

	Route	Qua	Distance	Cost/Km	Total Cost	Relativ
CHILDREN	A-B-C-	300	1.5	230	103500	1.00
ELDERLY	A-B-C-	500	4	1304.02	2608040	25.20
PHYSICAL LIMITED	A-F-D-G	480	1.5	1500	1080000	10.43
COGNITVE LIMITED	A-B-C-	350	3.5	849.9	1041128	10.05
LANGUAGE LIMITED	A-C-E-G	200	1	1299.6	259920	2.51
AUDITORY LIMITED	A-B-C-	100	2.5	866.4	216600	2.09
VISUAL LIMITED	A-F-E-	150	2.5	1990	746250	7.21
TEMPORARY LIMITED	A-C-D-	189	3	650	368550	3.56
PREGNANT	A-B-C-	488	9.6	1016	4759757	45.99
INDEBRIATED	A-B-E-G	400	1	1869	747600	7.22
PARAPLEGIC (PERSONS	A-B-C-	265	3.5	2649	2456948	23.74

The efficiency of the current prescribed average route (of ABCEDFG) was established again, under this scenario, using the From-To-Chart technique. The manipulation and the results are found in Table 6.

Table 6: *current layout from-to-chart for second scenario*

	A	B	C	D	E	F	G	Total point	Penalty Point
A	X X	115. : 115	6.1: 12.2	0	0	7.2: 36	0	129	163.2
B	0	XXX	108.1: 108.1	0	9.7: 29.1	0	0	118	137.2
C	0	0	XXX	3.6: 3.6	69.7: 139.4	38.4: 115.2	0	111.6	258,2
D	0	0	0	XXX	0	3.6: 7.2	71.2: 213,6	74.8	220.8
E	0	0	0	0	XXX	46: 46	41: 82	86.7	128
F	0	0	0	25.2: 100.8	7.2: 14.4	XXX	17: 17	49.1	132.2
							SUM	568.6	1039.6

From table 6, the Efficiency of the current average routing (ABCDEFG) is 568.6/1039.6= 54%. It can be seen that due to this new dispensation of giving different attentions to commuters of different types, the efficiency of the current route has dropped from 55% to 54%. This shows that the layout or facilities is fast becoming obsolete under the current dispensation.

Using the proposed new average routing of ABDECFG, the principle of From-To-Chart was applied again to determine the efficiency of the route. The results in Table 7 below were obtained. It should be noticed that the efficiency of the proposed layout or route shows significant improvement from 54% to 65%. This indicates a service delivery satisfaction and costs improvements. Thus, this indicates that there exists an enormous potential to improve on service delivery by employing the From-To-Chart techniques when service has to be rendered to individuals who move from one department to another. Comparing the improved layouts under this scenario 2 and previous scenario 1, the impacts of cost per distance or rewards for services rendered could be seen i.e. the efficiency has been dropped from 75% to 65%.

Table 7: *Improved layout From-to-chart for scenario two*

	A	B	C	D	E	F	G	Total Point	Penalty Point
A	XXX	104.2: 104.2	14.6: 29,2	10.4: 31.2	2.5: 10	7.2: 36	10.4: 62.4	149.4	273
B	0	XXX	95: 95	0	7.2: 21.6	2.1: 8.4	0	104.2	125
C	0	0	XXX	50: 50	24: 48	35.2: 105.6	1: 4	109.5	207.6
D	0	0	0	XXX	0	14: 28	0	14	28
E	0	0	0	0	XXX	46: 46	41: 81.2	87	128
F	0	0	0	0	7.2: 14.4	XXX	97.3: 97.3	104.5	111.7
G	0	0	0	0	0	0	XXX	0	0
							SUM	568,6	873.3

From Table 7, the efficiency of this prescribed flow pattern under *scenario 2* is (sum of Total point) divided by (sum of penalty point) =568.6/873.3= 65%

The next thing to do is to propose how the train station should be laid out under the two scenarios. This was achieved by obtaining flow between charts, the activities relationship charts and then the block diagram whose results are depicted from table 8 through to table 11, and diagram 1& 2.

The flow-between chart entries are obtained by assuming that the travel distance from A-to-B is the same as the distance between B-to-A, and hence the cost is the same for either direction of movement. This was done for flow between all the departments per passenger type, and the sum of all the movements between pair of departments for the entire passenger types were recorded as shown in Table 8 and Table 9.

Table 8: *Representation of flow between activities for scenario one*

	A	B	C	D	E	F	G
A	XXX	115,3	6.0722	0	0	0	0
B		XXX	109.08	0	9.7345	0	0
C			XXX	3,5609	69.727	38,35	0
D				XXX	0	0	71.186
E					XXX	53.198	40.683
F						XXX	16.713
G							XXX

Table 9: *Representation of flow between activities for scenario two*

	A	B	C	D	E	F	G
A	XX	104.2	14.6	10.4	2.5	7.2	10.4
B	0	XXX	95	0	7.2	2.1	0
C	0	0	XXX	49.5	24	35.2	1
D	0	0	0	XXX	0	14	0
E	0	0	0	0	XXX	53,2	40.7
F	0	0	0	0		XXX	97.3
G	0	0	0	0	0	0	XXX

The activity relationship chart was obtained by extracting the flow-between entries, ranking them in decreasing order of magnitude and then allocating the closeness values to them also in decreasing order from Absolutely important to Unnecessary. The closeness values were entered back into the flow between chart to obtain the activity relationship chart given in Table 10 and Table 11.

Table 10: *Activity relationship chart for scenario one*

DPT	A	B	C	D	E	F	G
A	XXXX	A	O	U	U	U	U
B		XXXX	A	O	O	U	U
C			XXXX	U	E	I	U
D				XXXX	U	U	A
E					XXXXX	E	E
F						XXXX	I
G							XXXXX

Table 11: *Activity relationship chart for scenario two*

	A	B	C	D	E	F	G
A	XX	A	I	I	E	A	I
B		XXX	O	0	E	I	U
C			XXX	O	I	E	1
D				XXX	O	I	0
E					XXX	O	I
F						XXX	A
G							XXX

Block diagrams are a graphic representation that gives a visual interpretation of how different departments should be placed in the train station. This is shown in diagrams 1 (scenario 4.2.2) and diagram 2 (scenario 4.2.3) with a scale of 1:500.

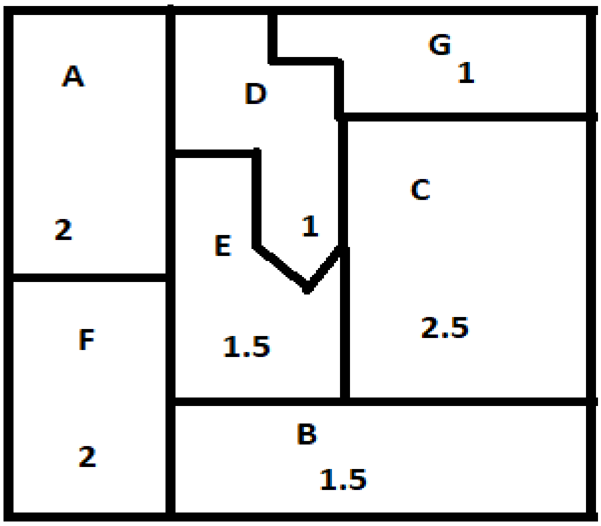


Diagram 1: *Block diagram for a proposed layout for scenario one*

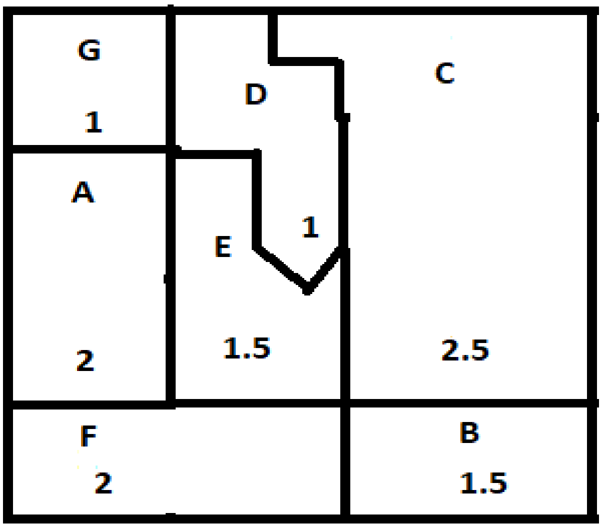


Diagram 2: *Block diagram for a proposed layout for scenario two*

The following paragraph is repeated so as to refresh the mind. The passengers were observed from the taxi rank with processing departments labelled as follows: A entrance to the taxi rank, B ablutions which cater for normal passengers and the disabled passengers, C retail (Game shopping store), D business lounges, E Shosholoza premier classes, F medical centre and G which is the exit to train station platform on which passengers catch a train to various destinations.

In the first scenario where cost was not taken into consideration it was seen that distance travelled could be used to indicate the efficiency of flow in a facility. The current layout's efficiency is 55%, which after re-arranging the layout so that the distance travelled between departments could be decreased the efficiency then increased to 75%. If people have to travel long distance between facilities, then this could impact the deterioration of the facilities as people are kept in the facilities longer.

In the second scenario where cost was taken into consideration; it was observed that the current layout's efficiency is 54%. This gives an indication that the train station loses more money to cater for various passenger requirements in their facilities since the facilities is not being used effectively. In this research a remedy has been established were a new layout is being proposed. The new layout gives an efficiency of 65%. In the second scenario it is seen that an improved layout will decrease unnecessary costs and bring about an increase on return on expenditures. It also promotes ease of facility maintenance. Importantly the passengers will be satisfied since their needs will be met.

4.4 Algorithmic Approaches

A wide range of algorithms for grouping departments to form cells or clusters was presented by Singh and Rajamani (1996). This includes the Direct Cluster Algorithm (DCA), which was employed in this project to also obtain an improved layout. The department-passenger matrix for the 11 different types of passengers and 7 departments is given in table 12. Applying the techniques of DCA algorithm yielded results presented in table 13 through table 16.

DCA algorithm combines processes and therefore reduces bottlenecks or conflicts. In general, conflict or bottleneck exists if the grouping of facilities (or departments) to form cells (or clusters) results in a need for a department to render services to passengers who fall into two or more different cells. Where bottleneck condition or conflict exists, the disruptive effects are minimized by locating bottleneck departments at the boundary between cells or by duplicating the conflicting departments and placing them in both cells. Alternatively, passengers that require a service by the bottleneck department have to be re-examined to determine if alternative approach of rendering of service can be used such as outsourcing of that particular service. Perhaps some services can be redesigned so that other departments can be used to serve passengers. If no better alternative is available, then the possibility of outsourcing the facilities to render a service to passengers is considered. The procedure for the DCA is outlined in chapter 3 whose practical steps are repeated and presented below to avoid flipping to pages behind.

4.4.1Step 1: *Completing the Machine-Part Matrix* *(specifically the service department – passenger matrix in our particular case)*.

This was completed by assigning 1s and blanks such that a 1 indicates the passenger was served at that particular department and a blank indicates that the department was not used to assist the particular passenger. This is presented in table 12.

Table 12: *Machine (or service department) – part matrix*

	A	B	C	D	E	F	G
CHILDREN	1	1	1			1	1
ELDERLY	1	1	1	1		1	1
PHYSICALLY LIMITED	1			1		1	1
COGNITVE LIMITED	1	1	1			1	1
LINGUISTIC LIMITED	1		1		1		1
AUDITORY LIMITED	1	1	1			1	1
VISUALLY LIMITED	1			1	1	1	1
TEMPORARY LIMITED	1		1	1		1	1
PREGNANT	1	1	1	1	1	1	1
INEBRIATEDPERSON	1	1			1		1
PARAPLEGIC (PEOPLE ON WHEELCHAIRS)	1	1	1		1		1

4.4.2 Step 2. (a): *sum the 1s in each row and column.*

The 1s in each column and each row of the department-passenger matrix were summed. This procedure led to table 13.

Table 13: Result of summing *1's in each row and each column*

	A	B	C	D	E	F	G	Total

CHILDREN	1	1	1			1	1	5
ELDERLY	1	1	1	1		1	1	6
PHYSICALLY LIMITED	1			1		1	1	4
COGNITVE LIMITED	1	1	1			1	1	5
LINGUISTIC LIMITED	1		1		1		1	4
AUDITORY LIMITED	1	1	1			1	1	5
VISUALLY LIMITED	1			1	1	1	1	5
TEMPORARY LIMITED	1		1	1		1	1	5
PREGNANT	1	1	1	1	1	1	1	7
INEBRIATEDPERSON	1	1			1		1	4
PARAPLEGIC (PEOPLE ON WHEELCHAIRS)	1	1	1		1		1	5
	11	7	8	5	5	8	11	55

4.4.2. Step 2.(b) *Ordering the rows and columns.*

Following the summing of 1s in each row and column was the ordering of the rows (top to bottom) in descending order of the number of 1s in the rows and ordering the columns (left to right) in ascending order of the number of 1s in each. Where ties existed, the ties were broken in descending and ascending orders of number of 1s respectively. This led to table 14

Table 14: Result of *ordering the column in ascending order and rows in descending order*

	D	E	F	C	B	A	G	Total
PREGNANT	1	1	1	1	1	1	1	7
ELDERLY	1		1	1	1	1	1	6
COGNITVE LIMITED			1	1	1	1	1	5
AUDITORY LIMITED			1	1	1	1	1	5
VISUALLY LIMITED	1	1	1			1	1	5
TEMPORARY LIMITED	1		1	1		1	1	5
PARAPLEGIC		1		1	1	1	1	5
CHILDREN			1	1	1	1	1	5
LINGUISTIC LIMITED		1		1		1	1	4
PHYSICALLY LIMITED	1		1			1	1	4
INEBRIATED PERSONS		1			1	1	1	4
Total	5	5	8	8	7	11	11	

4.4.3. Step 3: *Sorting the columns.*

Beginning with the first row, all columns having a 1 in the first row were shifted to the left of the matrix. The process was continued, row-by-row, until no further opportunity existed for shifting columns. The result below was obtained.

Table 15: Result of sorting the columns or shifting the columns to the left*s*

	D	F	A	C	G	B	E
PREGNANT	1	1	1	1	1	1	1
ELDERLY	1	1	1	1	1	1	1
COGNITVE LIMITED		1	1	1	1	1	
AUDITORY LIMITED		1	1	1	1	1	
VISUALLY LIMITED	1	1	1		1		1
TEMPORARY LIMITED	1	1	1	1	1		
PARAPLEGIC			1	1	1	1	1
CHILDREN		1	1	1	1	1	
LINGUISTIC LIMITED				1	1	1	1
PHYSICALLY LIMITED	1	1	1		1		
INDEBRIATED PERSON			1		1	1	1

4.4.4. Step 4: ***Sorting the rows.***

Column by column, beginning with the leftmost column, rows were shifted upwards and when opportunities existed blocks of 1s were formed resulting in:

Table 16: Result of *shifting rows upward*

	D	F	A	C	G	B	E
PREGNANT	1	1	1	1	1	1	1

ELDERLY	1	1	1	1	1	1	
TEMPORARY LIMITED	1	1	1	1	1	1	
VISUAL	1	1	1		1		1
PHYSICALLY LIMITED	1	1	1		1		
CHILDREN		1	1	1	1	1	
COGNITVE LIMITED		1	1	1	1	1	
AUDITORY LIMITED		1	1	1	1	1	
PARAPLEGIC			1	1	1	1	1
LINGUISTIC LIMTED			1	1	1		1
INEDEBRIATED PERSON			1		1	1	1

4.4.5. Step 5: *Forming cells.*

Opportunities were searched to form cells such that all processing for each passenger occurs in a single cell or in cells closer to each other, which led to

Table 17: *Cells formed after matrix*

	D	F	A	G	C	B	E
PREGNANT	1	1	1	1	1	1	1
ELDERLY	1	1	1	1	1	1	
TEMPORARY LIMITED	1	1	1	1	1	1	
VISUALLY LIMITED	1	1	1	1			1
PHYSICALLY LIMITED	1	1	1	1			
CHILDREN		1	1	1	1	1	
COGNITVE LIMITED		1	1	1	1	1	
AUDITORY LIMITED		1	1	1	1	1	
PARAPLEGIC			1	1	1	1	1
LINGUISTIC LIMITED			1	1	1		1
INEDEBRIATED PERSON			1	1		1	1

Results from Table 17 indicate that the entrance (A) and exit (G) of the train station could have been placed close to each other since this would have eliminated congestion in the train station. It would have also allowed for passengers not to spend much time in the facilities, as they could have entered and left the facilities quicker, covering shorter distances. Centralising Department A (entrance) and Department G (exit) could have made it easier for passengers travelling through Departments D and F to not block passengers travelling through Departments C, B and E.

Passengers who follow the route A, D, F and G will not require assistance to travel in the facilities, thus requiring shorter time and distance to travel. An elevator that could allow access to Departments E, B and C was recommended to assist passengers to travel backwards to the exit e.g. pregnant women can travel from E, B and C.

4.5 Simulated Annealing

Modelling and simulation play a vital role in the modern life (Pace, D 2004) as they mimic the behaviour of the real system and they are essential to the effective design, evaluation and operation of new systems. Simulated annealing was used in this project to compare different periods' efficiencies so as to decide on the layout that is suitable for the commuter rail system under the different peak periods. Table 18 gives the number of passengers for of the different peak periods for different passengers. As reported by Anastasia L. *et.al* (2015), the differentiating factors to these conditions should be passenger density, passenger attitude and route familiarity. This project, passenger density or number was used in the simulated annealing while passenger attitude and route familiarity were used in in conjunction with the discussion of the outcome of the simulated annealing. Data was collected over a period of two months from Passenger Rail Agency of South Africa managerial foot count reports and also by direct observations.

Table 18: *A number of passengers at train station*

	06-09am	**09-12am**	**12-3pm**	**03-**	**06-**	**Total**
CHILDREN	90	68	34	98	10	300
ELDERLY	150	55	63	182	50	500

PHYSICAL LIMITED	143	75	53	121	88	480
COGNITVE LIMITED	43	91	130	60	26	350
LINGUISTIC LIMITED	70	40	60	20	10	200
AUDITORY LIMITED	20	12	32	24	12	100
VISUALLY LIMITED	20	64	40	15	11	150
TEMPORARY LIMITED	51	31	44	43	20	189
PREGNANT PERSONS	40	130	202	86	30	488
INEBRIATED PERSON	13	50	86	100	151	400
WHEELCHAIR (PARAPLEGIC)	43	62	82	52	26	260
ABLED PERSONS	600	200	300	650	200	1950

A column-by-column combination was considered, and the from-to-chart technique was applied to determine different efficiencies for different peak periods. The column-by-column combination was constrained by the following facts. Abled persons and children were bound by the requirements of their jobs e.g. children and abled persons had to go to school or work respectively in the morning and come back in the afternoon. At mid-day passengers who required assistance felt that is was convenient for them to use the train station at that time for safety reasons and to be assisted in order for them to utilise train facilities and resources happily. Dormant period occurred at night where a smaller number of passengers used the train station, however this period layout would not be affected the results obtained for the effective layout as the layout that effectively assists passengers during peak periods would still effectively assists passengers at this time.

Scenario 4.5.1 (Peak period from 6:00am to 9:00am)

During the first peak period, which was from 6:00am to 9:00am, passenger volumes increased at the train stations as also observed by Swart P (2016). In the morning peak, commuters moved with more urgency in order to arrive in time at work, school, etc. During this time, it was noticed that passengers used the same train station to reach the same destination, day after day and therefore were familiar with their habitual routes. This type of passengers did not pay attention to their surroundings as they rely on their travelling experience. It was observed that inebriated, auditory and visually limited persons were less at the train station at this time due to crowding. Commuting at this time could have caused discomfort and risks for these people.

Table 19: *Representation of flow between activities between 6-9am peak period*

	A	B	C	D	E	F	G	TOTAL	PP
A	XXX	67.5 67.5	9.4 18.8	13.2 39.6	5.0 20	4.1 20.5	14.5 87	113.7	253.4
B	0.0	XXX	64.7 64.7	0.0 0.0	1.0 3.0	1.8 7.2	0.0 0.0	67.5	74.9
C	0.0	0.0	XXX	20.2 20.2	16.4 32.8	37.4 112.2	0.0 0.0	74.0	165.2
D	0.0	0.0	0.0	XXX	0.0 0.0	17.3 34.6	0.0 0.0	17.3	34.6
E	0.0	0.0	0.0	0.0	XXX	16.1 16.1	25.3 50.5	41.3	66.6
F	0.0	0.0	0.0	0.0	4.1 8.2	XXX	72.6 72.6	76.7	80.8
G	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0
							SUM	390.5	675.5

Table 19 presents the From-To-Chart technique used to measure the effectiveness of the prescribed sequence of flow, which gave 390.5/675.5 = 58% efficiency. The layout efficiency of the prescribed route ABCDEFG was calculated by dividing the sum of the total points by the sum of total of penalty points. The improved route was proposed by minimising back tracking i.e. by bringing departments with high penalty points closer to each other to get a new route.

<u>Scenario 4.5.2</u> (Peak Period from 09 am-12midday)

The second peak period occurred between 09-12midday. During this time, most of the people with special needs began to use the commuter rail facilities as there was less crowding. There was a decrease in volume of auditory, linguistic and temporary limited persons. These people in most cases relied on other passengers to commute effectively in train stations. It was also a time where there were less enabled passengers who can offer assistance to them. However, there were a high number of physical, cognitive and pregnant people during this time at the train station. Table 20 presents the From-To-Chart analysis whose efficiency was found to be 84%.

Table 20: *Representation of flow between activities between 9-12am peak period*

	A	B	C	D	E	F	G	TOTAL	PP
A	XXX	95.9 95.9	14.1 28.2	7.2 21.6	3.2 12.8	13.6 68	8.2 49.2	142.2	275.7
B	0.0	XXX	90.8 90.8	0.0 0.0	24.5 73.5	1.1 4.4	0.0 0.0	95.9	168.7
C	0.0	0.0	XXX	56.6 56.6	24.5 49.0	23.8 71.4	0.0 0.0	104.9	177
D	0.0	0.0	0.0	XXX	0.0 0.0	54.0 108	44.3 132.9	98.3	240.9
E	0.0	0.0	0.0	0.0	XXX	54.0 54.0	44.3 88.5	98.3	142.6
F	0.0	0.0	0.0	0.0	13.6 27.1	XXX	44.4 88.7	58	115.8
G	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0
							SUM	553.3	940.6

Scenario 4.5.3 (Peak Period from 12pm-03pm)

The peak period between 12-03pm had an increased number of cognitive, pregnant and inebriated persons. However, because it was during lunch period for most people, the volume of people increased as most people were using food facilities, ATM machines etc. There was lesser number for children as they were in schools and the auditory people who their hearing might be affected by the loud noise. The efficiency of this period was calculated (see table 21) to obtain 73%

Table 21: *Representation of flow between activities between 12-03pm*

	A	B	C	D	E	F	G	TOTAL	PP
A	XXX	280.4 280.4	41.3 82.6	10.2 30.6	6.6 26.4	17.0 85	10.2 61.2	365.6	5662
B	0.0	XXX	260.8 260.8	0.0 0.0	13.7 41.1	5.9 23.6	0.0 0.0	280.4	325.5
C	0.0	0.0	XXX	175.3 175.3	64.8 129.6	62.0 186	0.0 0.0	302.1	490.9
D	0.0	0.0	0.0	XXX	0.0 0.0	17.5 35.0	0.0 0.0	17.5	35.0
E	0.0	0.0	0.0	0.0	XXX	168.0 168.0	102.1 204.2	270.1	372.2
F	0.0	0.0	0.0	0.0	17.0 34	XXX	252.3 252.3	269.3	286.3
G	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0
							SUM	1505.0	2076.1

Scenario 4.5.4 (Peak Period from 3:00pm-6:00pm)

During the fourth peak period from 3:00pm to 6:00pm, passenger volumes increased at train stations (Swart P 2016). Commuters moved with more urgency in order to get home as most of them were from places such as work and school. During this time what was noticeable with passenger flow it is similar to the first peak period where passengers used the same train station to reach the same destination, day after day and therefore were familiar with their habitual routes. This type of passengers did not pay attention to their surroundings as they relied on their travelling experience.

It was observed that linguistic, auditory and visually limited persons were less at the train station at this time due to crowding. Commuting at this time could have caused discomfort and risks for these people. The effectiveness of the prescribed period was measured, and it gave 61%, seen in table 22.

Table 22: *Representation of flow between activities between 03-06pm peak period*

	A	B	C	D	E	F	G	PP	TOTAL
A	XXX	96.5 96.5	10.1 20.2	10.5 31.5	2.3 9.2	2.9 14.5	11.8 70.8	242.7	134.0
B	0.0	XXX	87.3 87.3	0.0 0.0	7.2 21.6	2.0 8.0	0.0 0.0	116.9	96.5
C	0.0	0.0	XXX	35.5 35.5	18.5 37	43.4 130.2	0.0 0.0	202.7	97.4
D	0.0	0.0	0.0	XXX	0.0 0.0	13.7 27.4	29.6 88.8	116.2	13.7
E	0.0	0.0	0.0	0.0	XXX	32.3 32.3	29.6 59.2	91.5	61.9
F	0.0	0.0	0.0	0.0	2.9 5.8	XXX	91.4 91.4	97.2	94.3
G	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0
							SUM	867.2	497.9

Scenario 4.5.5 (Peak Period from 06:00pm-09:00pm)

The last peak period occurred between 06:00pm-09:00pm. There's less children, linguistic and visually limited people during this period. During this period, it was dark and it might have been a risk for these types of passengers to use the train facilities on their own. This period efficiency was calculated using the From-To-Chart technique to obtain 60% efficiency.

Table 23: *Representation of flow between activities between 06-09pm peak period*

	A	B	C	D	E	F	G	TOTAL	PP
A	XXX	96.5 96.5	10.1 20.2	10.5 31.5	2.3 9.2	2.9 14.5	11.8 59	134.0	230.9
B	0.0	XXX	87.3 87.3	0.0 0.0	7.2 21.6	2.0 8.0	0.0 0.0	96.5	116.9
C	0.0	0.0	XXX	35.5 35.5	18.5 37	43.4 130.2	0.0 0.0	97.4	202.7
D	0.0	0.0	0.0	XXX	0.0 0.0	13.7 27.4	29.6 59.2	13.7	86.6
E	0.0	0.0	0.0	0.0	XXX	32.3 32.3	29.6 59.2	61.9	91.5
F	0.0	0.0	0.0	0.0	2.9 5.8	XXX	91.4 91.4	94.2	97.2
G	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0
							SUM	497.8	825.8

Scenario 4.5.6 (entire day data)

Table 24 show the results obtained for the overall number of passengers at the train station for the whole day. The total number of different passengers was taken for all different peak periods. The efficiency of the entire day was determined to be 64%.

Table 24: *Representation of flow between activities of the overall passengers*

	A	B	C	D	E	F	G	TOTAL	PP
A	XXX	103.8 103.8	14.6 29.2	10.4 31.2	2.5 10.0	7.2 36	10.4 62.4	149.0	272.6
B	0.0	XXX	94.5 94.5	0.0 0.0	7.2 21.6	2.1 6.1	0.0 0.0	103.8	122.2
C	0.0	0.0	XXX	49.5 49.5	23.3 46.6	36.3 108.4	0.0 4.0	109.1	205
D	0.0	0.0	0.0	XXX	0.0 0.0	14.0 28.0	0.0 0.0	14.0	28.0
E	0.0	0.0	0.0	0.0	XXX	46.0 46.0	40.2 80.4	86.2	126.4
F	0.0	0.0	0.0	0.0	7.2 14.4	XXX	97.3 97.3	104.5	111.7
G	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0
							SUM	566.7	865.9

4.4.7 Deviation Analysis (Comparing the different peak periods efficiencies)

A deviation analysis was done for different peak periods and different efficiencies respectively. The efficiencies obtained for each peak period, which are 58%, 84%, 73%, 61% and 60%, were compared with the overall period efficiency of the train station. Results indicate that the efficiency obtained at the peak period 03-00pm-06-00pm should be used to design the layout of the commuter rail system as it matches the overall period efficiency.

PART 4 B

4.6. Mogale City

The below Table 25 indicates the data for the different types of passenger at different peak periods at Mogale City train station. The services rendered were identical to those of the Johannesburg Park Station, although not highly specialise (see diagram 3). From-To-Chart technique was followed in order to determine the efficiency of the current layout's route (ABCDEFHG) with current users (see diagram 3). Results that were obtained show 63% efficiency for the current scenario. However, there are more passengers who have indicated that they are willing to use the train station provided that its facilities cater for more passenger types. From then, a future projection was made by combining the numbers of current passenger and passengers who had shown interest in using the train station should it be improved. In line with this, the efficiency of the Mogale City train station will change to 59% for the projected future number of passengers. The efficiency for future projection is less than the current layout efficiency due to the fact that the current layout only caters for the mostly enabled persons, hence the high the number of passengers who doesn't have special needs. The improved route (after minimising back tracking for the future projection) should be AHBCEDFG whose efficiency would be 64%.

Table 25: *Different types of passengers at Mogale City train station at different peak periods*

	06-09am	**09-12am**	**12-3pm**	**03-06pm**	**06-09pm**	**Total Current**	**Total Willing**	**Future Project**
CHILDREN	75	48	28	56	8	215	400	615
ELDERLY	115	36	48	161	43	403	650	1053
PHYSICAL LIMITED	122	62	41	111	58	394	450	844
COGNITVE LIMITED	13	21	36	23	14	107	140	247
LINGUISTIC LIMITED	21	17	14	7	3	62	320	382
AUDITORY LIMITED	8	4	11	14	13	50	380	430
VISUALLY LIMITED	4	12	9	7	6	38	410	448
TEMPORARY LIMITED	44	23	32	27	7	133	250	383
PREGNANT PERSONS	28	52	86	43	19	228	290	518
INEBRIATED	6	27	52	66	73	224	260	484
WHEELCHAIR	2	6	7	2	1	18	281	299
ABLED PERSONS	501	116	173	350	89	1229	1800	3029

The departments are represented as follows:

A – Entrance

B- Retail shop (premier class)

C- Retail Shop (game shopping store)

D- Retail Shop (business lounge)

E 1 – Ablutions for females and E2 for males

F- Retail shop (and medical facilities

G-Exit to trains station platforms

H- Area manager’s office

Diagram 3:*Block diagram of the current Mogale City train station*

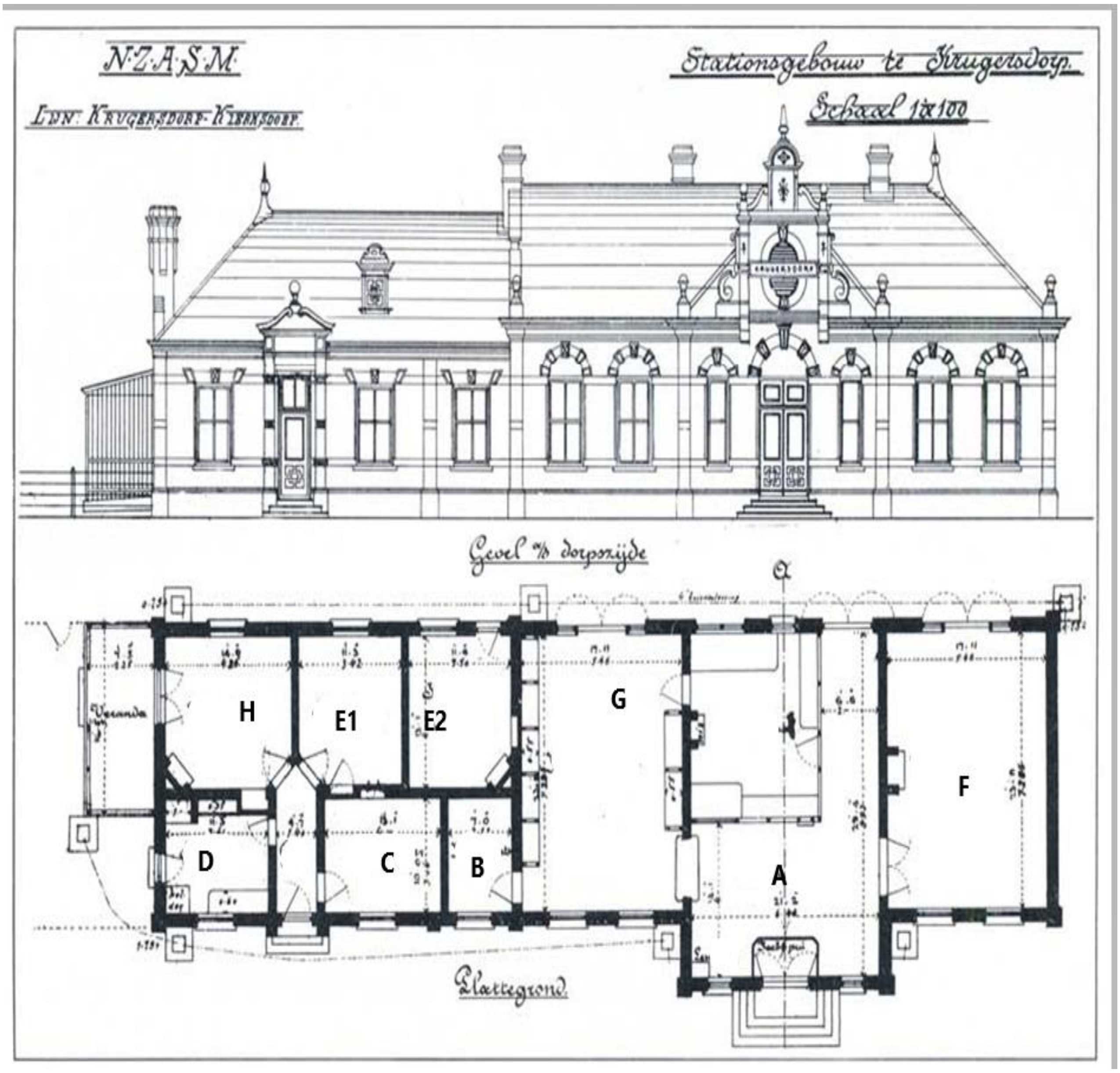
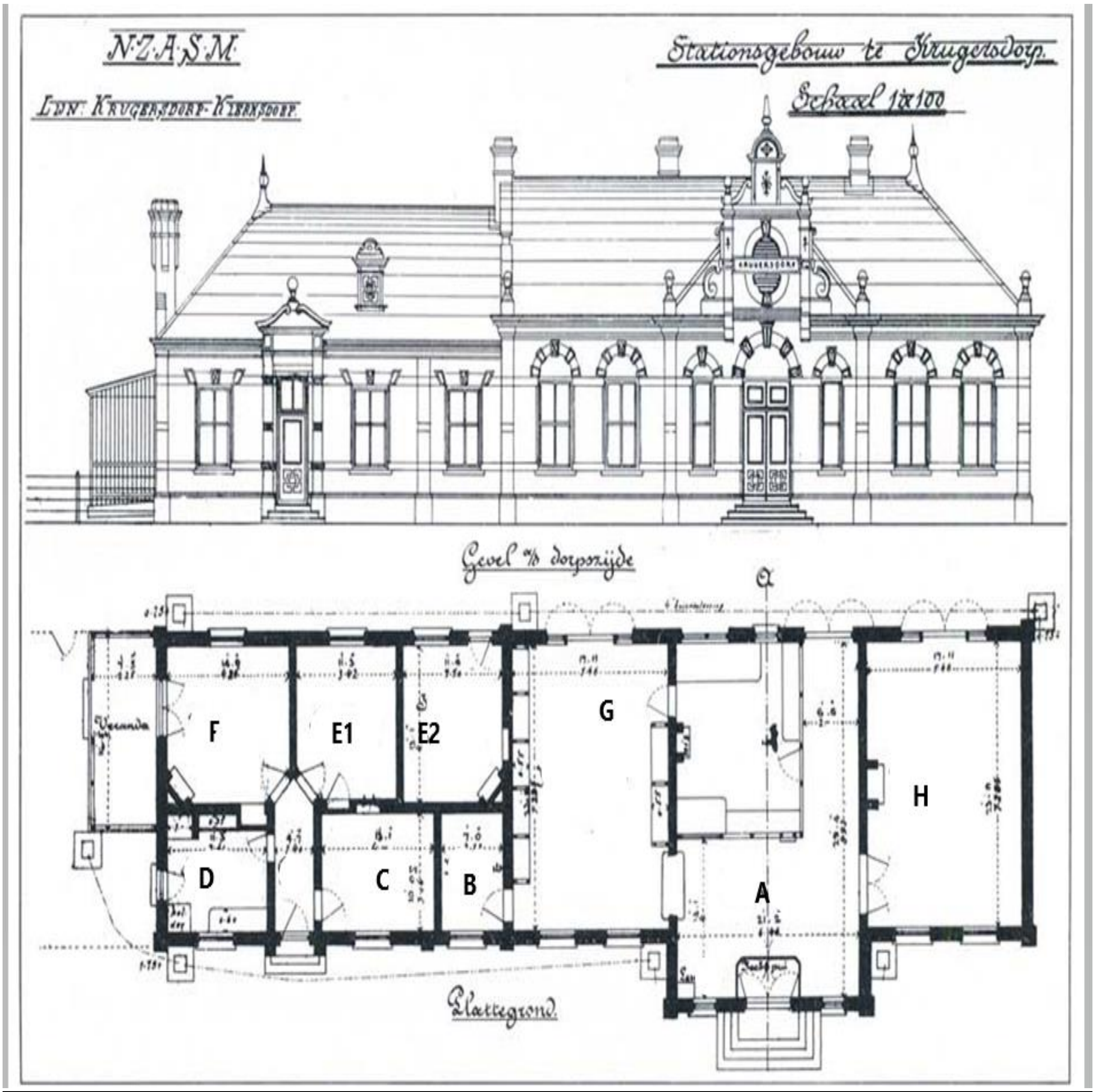


Diagram 4 gives a graphical display (i.e. block diagram) of how proposed departments should be placed at Mogale City train station. This was obtained by suggesting that department rendering service should exchange where they are placed or should be moved. It also seen that in this diagram all departments with similar processes are to be placed together e.g. department BCDF which are retail departments with added support services, AH are administrative departments, E1 and E2 which are ablution facilities and G which is the exit.

Diagram 4: *Block diagram for improved Mogale City Train Station Layout*



4. 7 SOME SELECTED FACILITIES TO BE PROVIDED AT MOGALE CITY

Different approaches have applied on how to determine layout alternatives, which are effective. The following sections deal with facilities that should be provided to accommodate for passengers with special needs in the train station at Mogale City.

There are standards that are required to be followed when implementing facilities that cater for different passengers in a rail commuter system. The South African National standard provides requirements for compliance part S (facilities for persons with special needs) of the National Building requirements (SANS 10400). This is issued in terms of the National Building Regulation and Building standards (Act No. 103 of 1977).

The Passenger Rail Agency of South Africa (PRASA) also should ensure compliance with this national standard while improving train stations, which is documented in the Norms, Guidelines and Standard for station facilities (NGS) NGS 1997. The NGS was developed with the aim of integrating, standardizing, accelerating the planning, feasibility studies, approval of station infrastructure projects and execution of all station related projects for the South African Rail Commuter Corporation (SARCC) divisions and subsidiaries. Therefore, PRASA has a role to play in offering good services to its customers.

PRASA's primary responsibility is to effectively develop, manage rail related transport infrastructure, to provide efficient rail and road-based passenger transport services. This responsibility should be supported by a "total station management" approach that should be developed to enhance passengers' travelling experience. Thus, Mogale City train station should possess facilities as per the prescribed national standard (SANS 10400).

As reported by Tompkins *et.al* (2010), planning for personnel requirements should involve integrating barrier free designs and planning for, for example, employee parking, locker rooms, restrooms, food services, drinking fountains and health services. Below are some of the services and facilities that should be provided at the Mogale City train station to ensure that national regulations and personnel requirements are met.

4.7.1 Training

Technical staff that are responsible for maintaining, operating infrastructure and customer facing staff should be trained on disability awareness according to Williams, D (2017) to maintain a harmonious, collaborative and environment that is free from discrimination. It was also evident at the Johannesburg Park Station that having confident and well trained staff in disability awareness also increases productivity as more passengers were put at ease, which made them to spend money within the train station and making them more likely to return and use services offered at the train station.

4.7.2 Pre-Travel Information

Research conducted by Zhang *et.al* (2015) reports that pre-trip travel information provides travellers with various travel information and supports them to make better decisions on travel behaviour. Pre-travel information facilitates the understanding of the possible effects of the travel; improves system design and implementation strategies. Train station should be clearly and consistently signposted. In a country like South Africa, there are eleven official languages, more than one language can be used to ensure effective communication. For visually impaired passengers, the use of braille facilities should be available and information on routes should be provided via tactile paths, audible facilities, tactile signs and maps.

4.7.3 Security

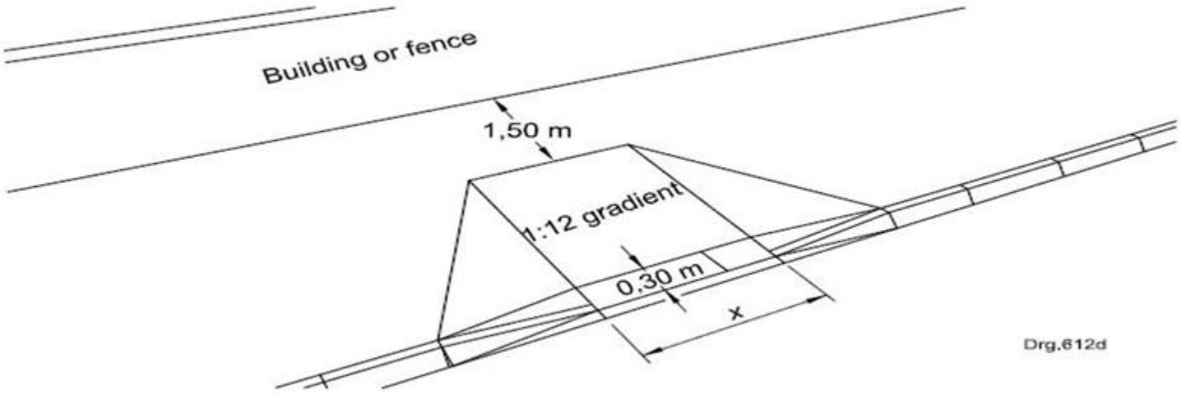
The purpose of security is to safeguard against criminal acts and protection of the rail commuter station infrastructure, personnel and passengers. The layout of corridors, entrances, service passages, closed circuit television cameras' positions for monitoring are important in determining the minimum space to avoid dangerous activities from occurring. The location of vending machines and banking machines (which are examples of some facilities that have high potentials of attracting criminals) must be carefully considered. Sufficient provision should be made for the safe and secure removal of money from ticket selling facilities especially during peak passenger activities. Access restrictions should be applied to or from the rail station area, except through formal access control points so as to reduce the risk inside the station area. Well-positioned access control points can be used for passengers to validate their tickets and to limit their risk factor.

4.7.4 Maintenance

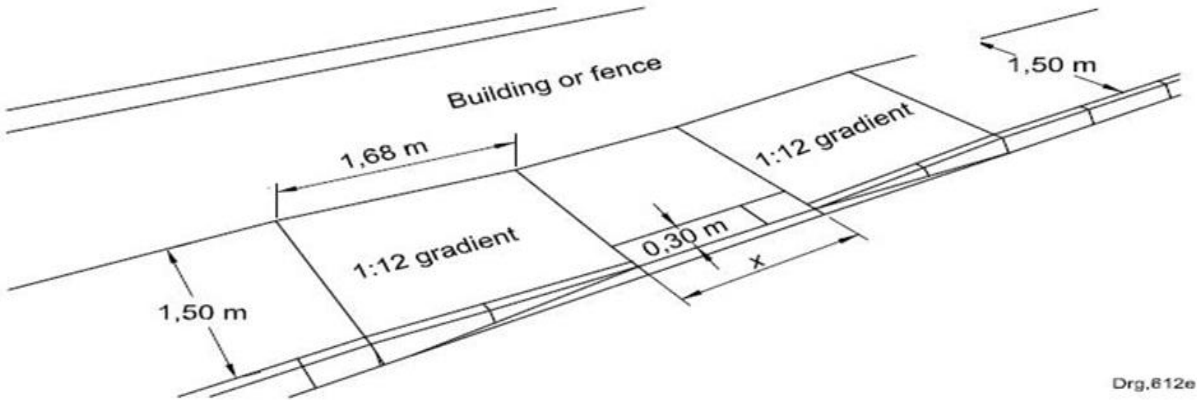
The Norms, Guidelines and Standards for station facilities (2014) reported that the maintainability of a station ensures that all components should be ready for use when needed and should be capable of performing its assigned functions through the commuting cycle, which includes peak, off peak and dormant periods as well as normal, abnormal and emergency modes. The maintenance of any element of a station should take cognizance of the rail passenger’s cycles and scheduled corrective and preventative maintenance duration should be integrated with the comfort, convenience and safety level of applicable regional passenger rail services.

4.7.5 Parking Facilities

The Norms, Guidelines and Standards for station facilities (2014:5,1-5) reported that entrances and routes to and from the stations should be sufficient to accommodate volumes and rates of arriving and departing pedestrians, mini buses, metered taxis, buses and other vehicles as determined by the transport model for the specific station. This includes possible influences of commercial development around the station. Drop off and pick up areas, holding areas, service areas, passengers’ day parking, personnel parking, delivery vehicle parking should also be accommodated according to their relevant rates and volumes. According to SANS 10400 part S “stop” and “drop” facilities should allow a person to be dropped off or picked up at an entrance to a facility without the need for vehicle to be parked. The area should be covered for weather protection. Figure 3 demonstrates how the accessible routes should be at road level and near to a kerb cut so that it is easy to get to the safety of the footpath. In cases where the accessible route is not at road level, the alignment of the kerb must allow vehicles to park against it. There must not be any level or height constraints that will impede the use of the stop and drop of facility. Kerbside stop and drop facilities should be where road gradients and camber causes are reasonably level e.g. 1:50 as a slope from the road with a steep camber causes difficulty for people using wheelchairs who have a side lift in their vehicles.



a) Ramp with kerbed sides (wide footpath)



b) Ramp with narrow footpath

Fig 3: *(a) Ramps with kerbed sides and (b) Ramp with narrow footpath*

As per SANS 10400 part S, the minimum distance from accessible route should be 6600mm and the minimum route width should be 1000mm preferably with a vehicle bay of 3500mm. The accessible route on a footpath width must be a minimum of 1500mm to allow transfer to and from a wheelchair without being obstructed by other pedestrians. In a facility that has multiple entrances; accessible parking bays should be dispersed and located closer to entrances. It is good practice according to SANS 10400 part S (2011) to allow maximum acceptable height of vehicle to be visible on the approach of a parking area since some people make use of vans or height roof cars, or wheelchair stowed on top of the vehicle. A minimum vertical clearance from entering the parking area to the accessible bay should be 2000mm. The minimum required number of accessible bays compared to the total number of parking bays is shown in the table 26.

Table 26*: Minimum required number of accessible bays* (SANS part S 2011)

Total Number of Bays	Minimum Required Number of Accessible Bays
1 - 25	1
26 - 50	2
51 - 75	3
76 - 100	4
101 - 150	5
151 - 200	6
201 - 300	7
301 - 400	8
401 - 500	9
501 - 1000	2% of total
1000 & over	20 + 1 for every 100 over 1000

According to SANS part *S* (2011), perpendicular parking is more preferable than angled bays. The dimensions of accessible parking bay should allow for transfers from a wheelchair on either side or rear of vehicle. The minimum bay width should be 3000mm and minimum access aisle should at least be 1000mm wide. If a kerb exists, dropped kerbs and ramps should be provided to link accessible parking bays to the accessible park way. The safety zone of the vehicle should provide access to the boot of the vehicle or for use of a rear hoist. Levels of accessible parking bays should not be steeper than 1:50 with no changes of level being preferable. Wheel stops can be also used to demarcate the vehicle area from the access aisle. Bollards may be used to provide adjacent access areas without the need to modify the layout of an existing parking area. Bollards may also be used to block a central parking space to create two accessible parking spaces. Figure 4 below illustrates the required parking layout.

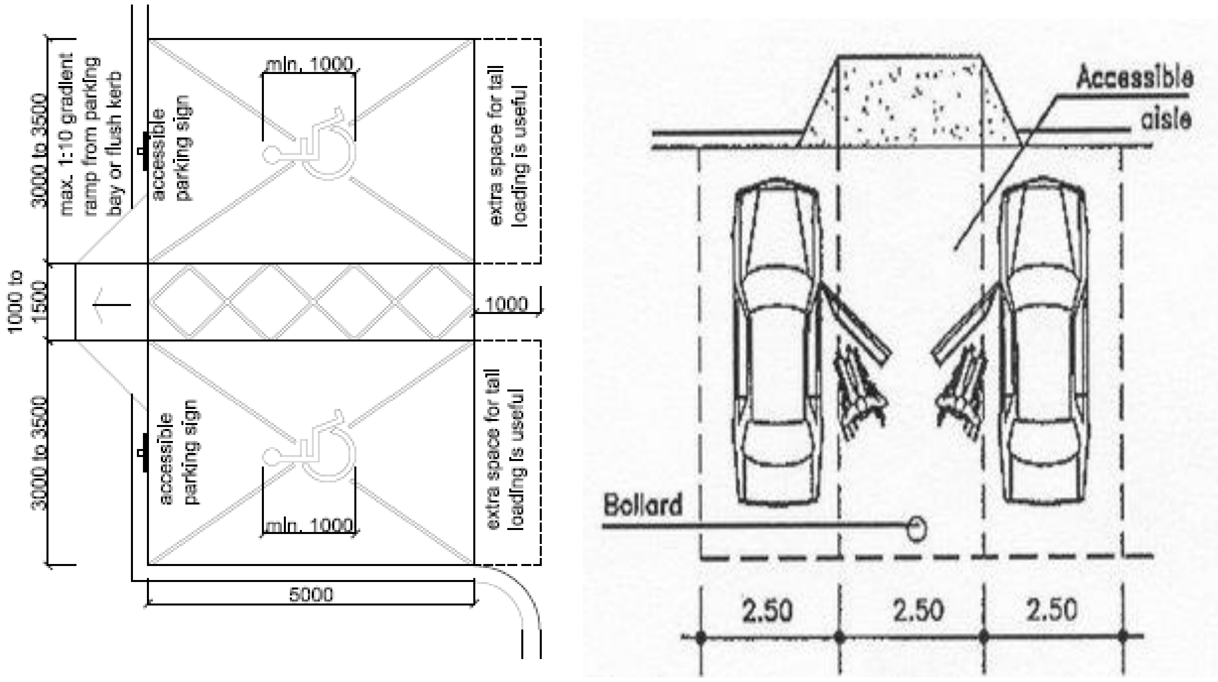


Fig 4: *Accessible Parking Bays*

4.7.6 Signage

Accessible parking bays should be indicated by signage in accordance with the South African Road Traffic Sign Manual (2012). As indicated in figure 5, international symbols of access should be exhibited at the main entrance and suitable positions to indicate route to facilities for persons with disabilities. As indicated in figure 6, embossed and braille signs are recommended in accessible toilets and at all toilet doors to identify whether unisex or single sex. They should be visually contrasting in dark and light colours. Where visually impaired persons live or work, then evacuation instructions should be provided in large print and braille (figure 7). It is also important that internal escape signage with its emergency lighting, should comply with South African National Standard (2011).

It is good practice to have a combination of upper- and lower-case letters as seen in figure 8. It is good not to have decorative fonts or italics but to have adequate font size. The location where the sign should be placed should be well thought of and the background should not be reflective. Figure 9 shows that signage in train stations should consist of, for example, safety information, instructions, warning prohibitions signs, train services, identification of station facilities, access routes and any call for assistance or call for information facilities. The lighting signs should allow visibility in all conditions and direction signs should have arrows attached to them as seen in figure 10.

Fig 5: *Signage* for *People on wheelchair*

Fig 6*: Signage for toilets*

Fig7: *Signage for Visually impaired people*

Fig 8: Combination of upper & lower cases

Fig 9: *Signage showing information to passengers*

Fig 10: *Signage showing direction and electronic devices*

Screen displays should always show complete station names. The displayed information should appear for a minimum of two seconds if scrolling is used and it is better to refresh the information than scroll. If information changes it must allow for enough time for people to comprehend and read the information given especially visually impaired and passengers with learning difficulties who may need more time. A good contrast and large text should be used for easy reading. For passengers on wheelchairs, low-level screens should be used in order for them to be able to view the information that is provided on the screen. Shade of screens should be provided from areas of glazing or light fittings to prevent reflections or alternatively matt screens can be used to prevent reflection. Figure 11 below is an example of a screen display that can be used in train stations.

Fig 11: *Screen Display*

Table 27 presents the appropriate colour relationship for signage.

Table 27: *Colour relationship for signage*

Background	**Signboard**	**Legend**
Brick or Dark stone	White	Black, dark green or dark blue
Light Brick or light stone	Black or Dark	White or yellow
Whitewashed walls	Black or Dark	White or yellow
Green Vegetation	White	Black, dark or green

4.7.7 Circular Path Walkways

According to South African National Standards 10400 (2011), footpaths and walkways provide a specific space for pedestrians to walk on. The kerbzone should be designed for drainage and to segregate pedestrians from streets. The sideway surface may be a patterned concrete bricks, stove paving or asphalt with a coarse aggregate finish. Rigid surfaces assist to resist indentation from forces applied by walking and reduce rolling resistance by a wheelchair or other wheeled vehicles. It is important for surface to be slip resistant, preventing shoes, crutch tips or tyres from sliding across the surface while bearing weight. It is advisable not to have cobbled finishes as they increase the amount of effort required to enable mobility, whilst also presenting tripping hazards. Tactile clues and colour changes should be provided to assist visually impaired and blind people to establish boundaries of the sidewalk and the presence of obstructions.

Cross gradients should be minimized as they create a challenge for wheelchairs or people using crutches to maintain a lateral balance. The force of gravity tends to pull or push wheelchair and person with a walking aid towards the kerb or lower pathway or street edge. For wheelchair passengers the pushing force required to counteract these effects will vary on each wheel rim, small on high side and large on the low side of the pathway. Forward momentum towards the kerb may require unequal hand braking on the wheels, leading to possible loss of control.

The below figure 12 indicates the effect of compound slopes on passengers with special needs, particularly people on wheels chairs. When travelling on a non-planar surface the front wheel of a wheelchair, pushchair or mobility aid can lose contact with the sloping surface, which can lead to a loss of balance and control.

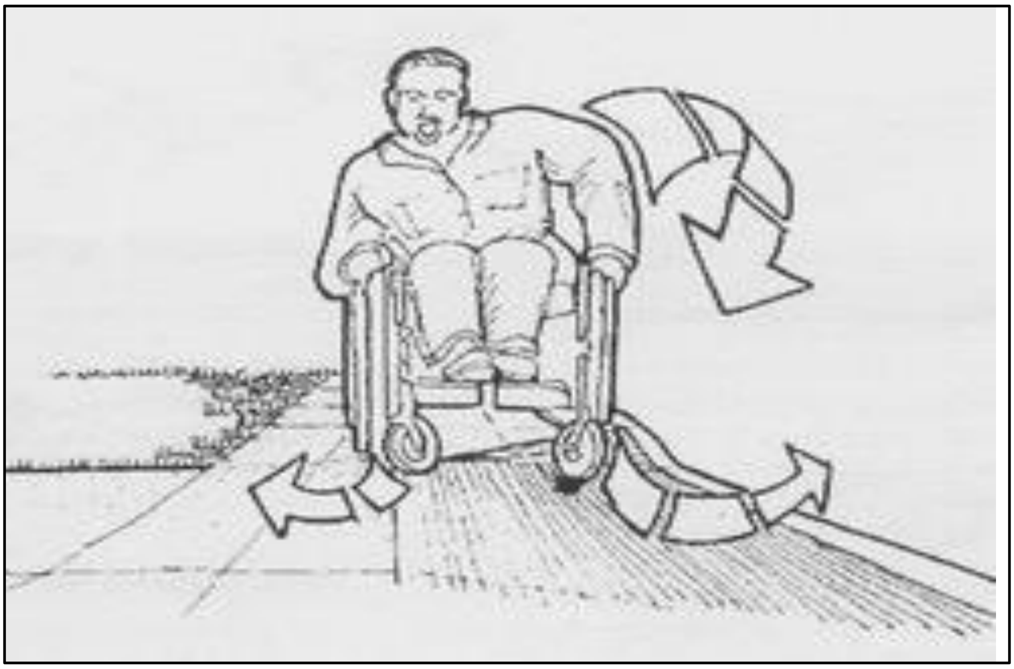


Fig 12: *Loss of balance and control by passenger on a wheelchair (SANS 10400).*

4.7.8 Corridors

Corridors should be safe and clear of obstructions as they provide access and form part of escape routes. If possible, equipment such as fire extinguishers should be recessed, as these projecting items are hazardous to people with sight impairments. SANS 10400 reports that columns and other projections into passenger circulation area should be avoided, if not they should be highlighted using contrasting colour tones.

As seen below in figure 13 the height and width of a corridor must exceed the space required to accommodate all pedestrian movement. As stated in South African National Standard (2011), the width of a corridor of a low traffic should not be less than 2200mm for bi-directional traffic and 1800mm for one-directional traffic. It should also allow manoeuvrability around corners i.e. change in direction less than 180º and U bends or changes in direction of 180º or more.

The height of a corridor should be unrestricted and not be less than 2100mm. There should not be protrusions of more than 5mm from the floor surface level measured over a distance of 6100mm. Where grating is installed, apertures should not exceed 13mm wide.

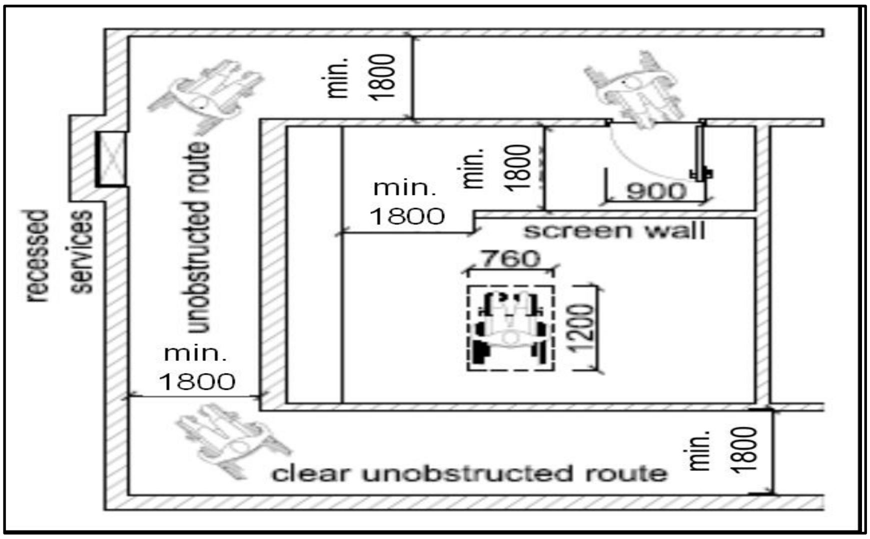


Fig 13: *An unobstructed corridor*

Corridors should allow passing places, where the width of the corridor is adequate. Figure 14 shows that if it is less than 220mm width, passing should be provided at intervals along the corridor. Passing places of at least 900mm width by 2000mm should be provided at intervals not exceeding 30mm and in a direct line if sight.

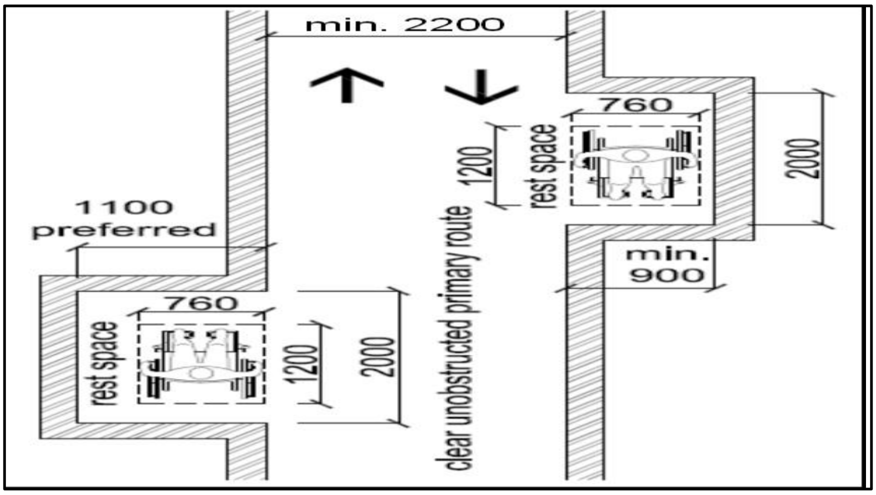


Fig 14: *Clear unobstructed route*

4.7.9 Tactile Indicators

Tactile ground surface indicators provide assistance to people with visual impairments with their orientation. Where normal or natural guidelines are not available, visual impaired or blind passengers use tactile indicators. Guide strips should be of contrasting colour as shown in figure 15 and 16. As per South African National Standard (2008) tactile indicators should be 10m in length, guidance should be provided by a tactile guide strip in an urban designed feature or surface that is constructed alongside accessible routes (see figure 16). The back edge of the tactile surface should be at right angle to the direction of crossing where the accessible route changes direction; there should be a gradual change in direction of the guide strip.

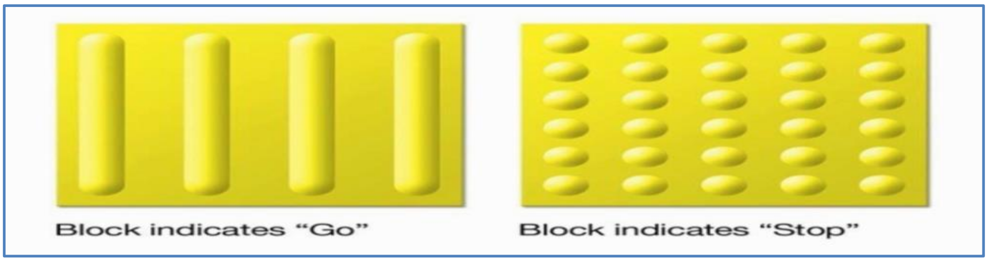


Fig 15: *Ribbed tile and knob tile indicators*

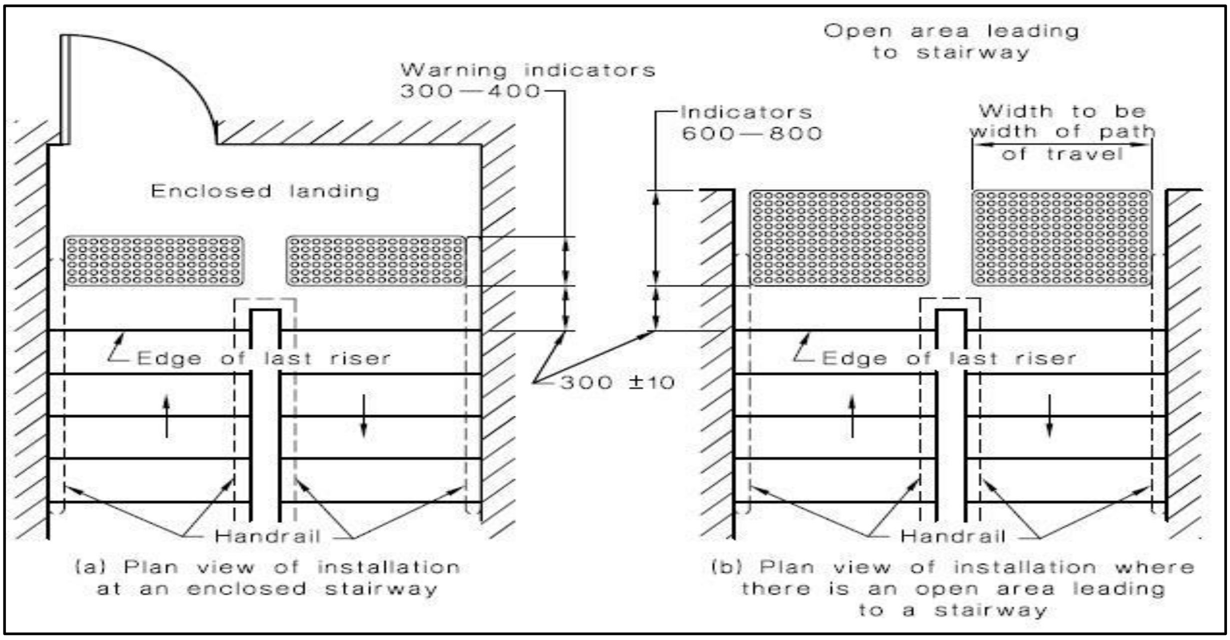


Fig 16: *The application of tactile indicators*

4.7.9 Lifts

Lifts provide solution to changing levels especially for those who do not wish to or cannot use the stairs or escalators. They can also be provided in preference to a very long ramp. As reported by PRASA (2014) Lift cars should be large enough to accommodate all users, including wheelchair users with reclining or particularly large motorised wheelchairs, wheelchair users who may have a limb or limbs extended, wheelchair users and their carriers. Lifts that are provided in train station should be able to accommodate a stretcher in case of emergency this is seen in figure 17. Passenger lifts that are provided to evacuate people with disabilities in an emergency situation should have an independent power supply and meet the relevant code of standards. A standard way or signpost should be used to show an intending user if the lift is not operational.

People with ambulant disabilities may require more time to enter the lift than provided. Therefore, there is a need for re-opening mechanism. The door leading edge must have an additional contact, which operates without causing a large force on any obstruction, which could otherwise cause a person with mobility impairments to be pushed and who may fall. Doors must be provided with a re-opening mechanism that will stop and re-open a lift car door automatically if the door becomes obstructed by an object or person.

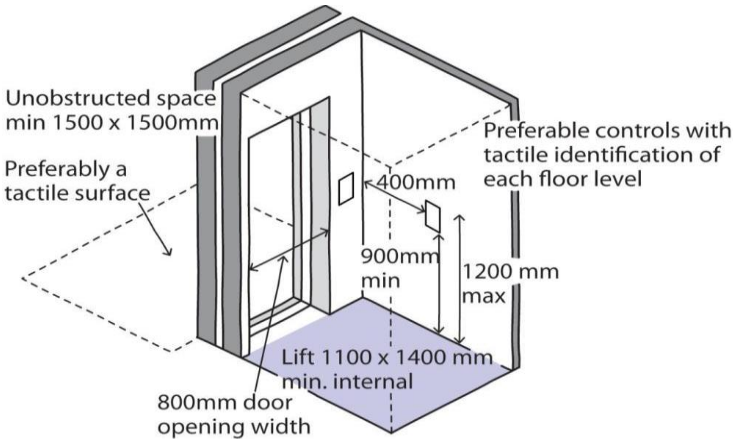


Fig 17: *A lift that caters for people with disabilities*

4.7.10 Ablution facilities

The layout of the ablution facilities should allow for its use by people with differing abilities. Accessible facilities should be provided in a separate unisex facility to allow for those users who are obtaining help from the opposite sex. Fittings such as vending machines, sanitary disposal units and waste bins should be recessed where possible so as not to obstruct people flow. The boxing in of pipes should be carefully considered so as not compromise manoeuvre space (see figure 18). The ablution facilities should be close to the train station building, with step free access route and linked to a footpath National Guide Standard (2014:5-48).

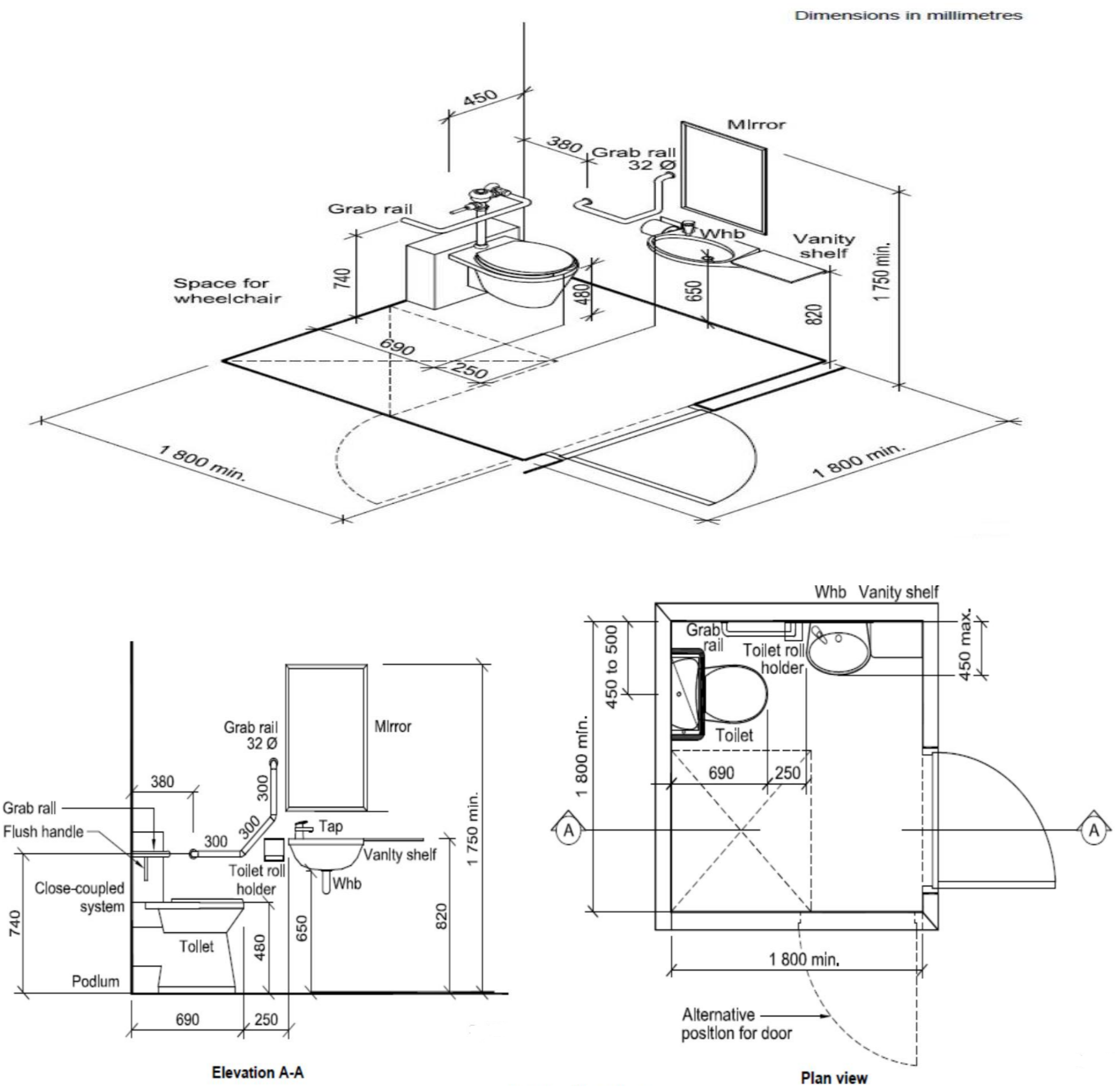


Fig 18: Ablution facility that caters for disabled passengers

4.7.11 Barriers

Barriers are used to control movement of people so that they follow a desired route. Barriers should be avoided, if possible, as they can become obstructions to people and increase the distance to be travelled. Barriers should not be placed within the path of travel and should have rounded edges to prevent injuries. Visibility should be afforded through the railings so that advance warning of the presence of people behind the railing is provided. Flexible rails should be avoided, as they do not provide any resting or leaning places for people. Staggered barriers across footpaths prevent conflict with other forms of traffic. Barriers should be constructed with vertical bar sections of 1200mm high and colour contrasted with their surroundings.

4.6.12 Facilities Recommended at PRASA-Mogale City

Table 28 below shows the dimensions of some of the recommended facilities for Mogale City train station to accommodate passengers with special needs. The facilities were obtained using given information on the level of activeness, available space (using measuring metrics), information about the locality found in reports and literature. The layout represented by diagram 5 demonstrates that to incorporate the recommended facilities which are presented in table 28, some of the departments should be reduced in size in order for the available space to be used effectively, otherwise the Mogale City train station will have to be expanded.

Table 28: *Recommended Facilities for PRASA-Mogale City*

Ticket Sales Facility Area Requirements	
Facility	**Area (m^2)**
Ticket Sales cubicle	3.9
Accessible sales cubicle (minimum 1)	3.9
Accessible sales cubicle (minimum 1)	4.5
Default Ticket sales (minimum 1)	4.9
Secure-lock ante-room	3
Supervisor Office	7.4
Strong Room	2
Cash up office	7.4
Kitchenette	6

Break Room	12
Male toilet	2.4
Female toilet	2.4
Public Ablution Area Requirements	
Facility	**Area (m²)**
Unisex accessible toilets	2.4
Unisex baby changing station	2.4
Male toilets	2.4
Female toilets	2.4
Administrative Offices & staff Accommodation Area Requirements	
Facility	**Area (m²)**
Senior Clerk/Supervisor office	8
Equipment Room	21.6
Kitchenette	6
Unisex Accessible toilets	3.7
Station control Room	9
Information Point	3.9
Reception & Lobby	9
First Aid/Infirmity	7.4
Area Manager	9
Station Manager	9
Meeting/Briefing Room	12
Admin store	8
Break room	2
Male Locker Room	3
Female locker room	3
Male Toilet	2.4
Female Toilet	2.4

Unisex Accessible toilets	2.4
Security Accommodation & System Requirements	
Facility	**Area (m²)**
Charge Office	9.8
Security Supervisor office	8
Security Office/Cell surveillance	5
Holding cells	5
Strong Room	2
Kitchenette	4
Break Room	2
Male Locker Room	3
Female Locker Room	3
Male Toilet	2.4
Female Toilet	2.4
Cleaners Accommodation Requirements	
Facility	**Area (m²)**
Cleaners office	3
Male Locker Room	6
Female Locker Room	6
Male Toilet	2.3
Female Toilet	1.8
Kitchenette	4
Break Room	2

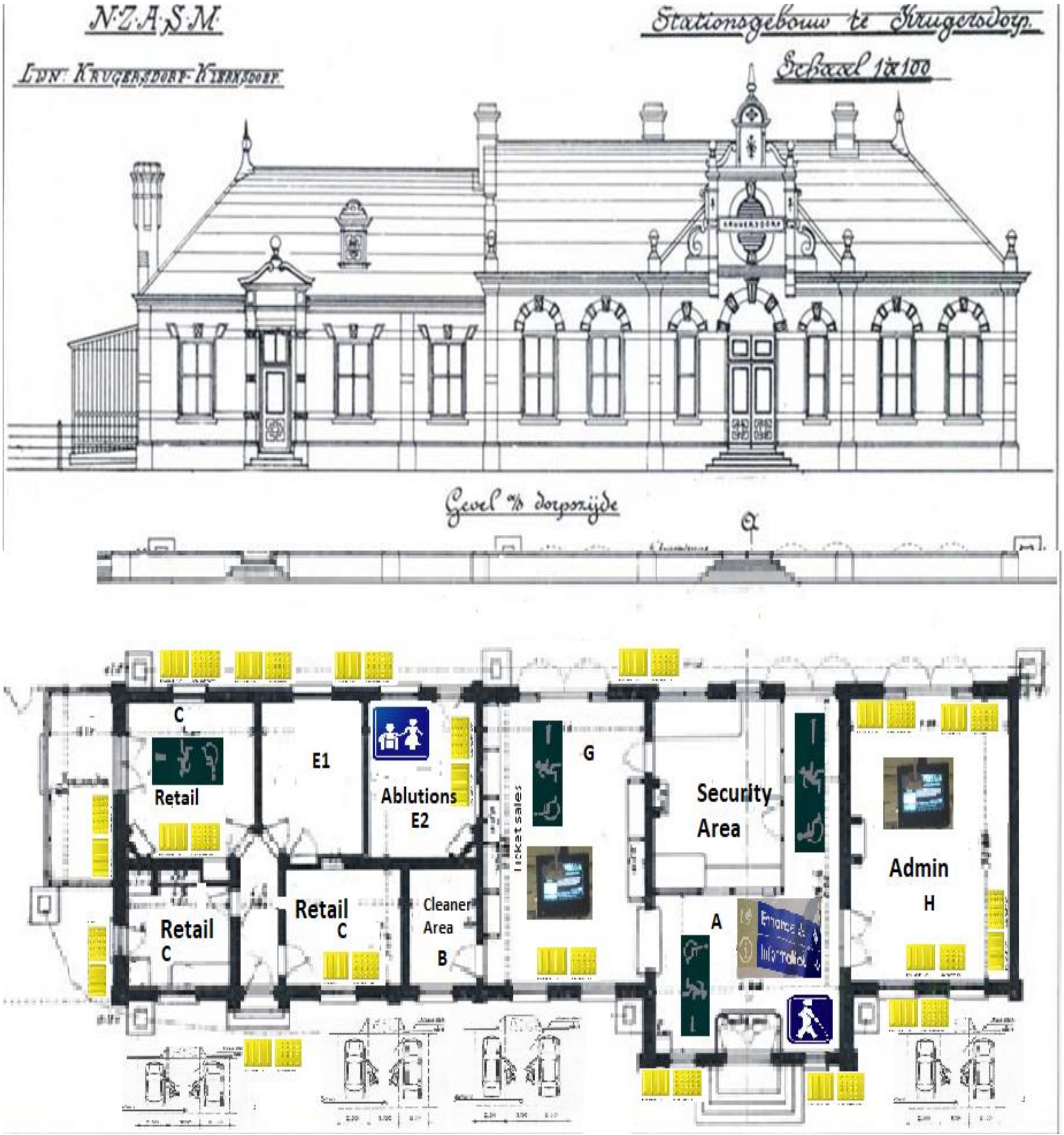


Diagram 5: *Block diagram for recommended Mogale City Train Station Layout with signage*

CHAPTER FIVE

5.1 CONCLUSION AND RECOMMENDATIONS

Commuter rail system's layout needs to be effective in order to meet passenger's expectations. More often the individuals' specific needs are not considered since the rule of the majority is mostly applied. As such, those designed commuter train stations soon become obsolete if additional constraints of giving variable priorities to various customer specific expectations are required. The situation is even worsened if variable rewards are required to render those services to customers with variable expectations.

Improving passenger's train station experience is crucial to the rail business where correlation between passengers and profitability has been widely advocated. It is important for train stations managers to further explore the train station service quality that will differentiate the success of the commuter rail system. This, thus, motivates the needs to explore the effective design or redesign of train station services.

It is essential to understand that universal designs require a framework of infrastructural and operational upgrading, especially where cost constraints restrict the development of complete universal design framework. Successful results were obtained in this project, as facilities that are required for the varying needs of passengers with special needs in a commuter rail system were determined. The employment of the DCA method assisted in determining the how departments should be grouped together in order to improve train station flow efficiencies. Also, the flow of commuters was also successfully achieved through the application of the From-To-Chart techniques for various scenarios. The application of simulated annealing assisted in obtaining an effective layout under different peak periods. A recommended train station layout for Mogale City is given under the implantations chapter. This layout gives two alternatives to improve the train station layout. In the first one, the current train stations building doesn't have to be demolished but different departments can be arranged (i.e. by moving or exchanging locations of departments) and special needs' facilities incorporated in manner that will allow effective flow and cater for various passenger needs. Alternatively, the building can be expanded as per the proposed new layout and additional facilities appropriately provided to accommodate for all passenger types. Positive results were obtained which indicate that the efficiency of Mogale City train's layout can be improved. By applying the methods presented in this research Mogale

City’s train can comply with the government’s public facilities requirements and most importantly all different passengers will be accommodated at different periods.

In summary, companies need to meet national imperatives. However, companies do not always have monetary resources at their disposal to meet the necessary requirements. To redesign a facility, one needs to consider elements such as flow systems, space requirements and flow relationships since they are essential elements to provide the foundation for facilities planning. The current Mogale City train station layout doesn’t meet the needs for all its passengers. However, results obtained in this project propose effective layout alternatives as solutions for redesigning the commuter rail system in order for it to meet its passenger’s needs. Results obtained thus show how flexibility in the layout design can be managed.

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Appendix

Redesigning a commuter rail system to accommodate passengers with special needs

Passenger's View on the Current Train Station Layout

	Yes	No	Unsure
Is the train station designed to meet the various needs of passengers?			
Does the current layout need to be redesigned to accommodate all the passengers			
Are you willing to use the train station should the train station layout be improved			

Passengers Satisfaction with train station layout

Highly Unlikely ←→ Very likely

	0	1	2	3	4	5	6	7	8	9	10
How likely currently will you recommend other train users to use this train station in relation to the layout											
What are the likelihood of being injured in the station in relation to the safety of the facility											
How likely will users easily avoid being trapped in how the layout is designed in case of emergency											

	N/A	Poor	Fair	Good	Very Good	Excellent
Train station layout structure is convenient for 24/7 operation						
The current facility walkaway makes it easier to access						
Station is well maintained and clean at all times						
In case of emergency, the facility have the standing emergency point which are easily accessible						
All group of train passengers are sufficiently accommodated with the currently layout						
The safety boards are clearly visible to all the train users						
Overall satisfaction with train station layout						