FACILITY PLANNING AND LAYOUT DESIGN OF A RAILWAY STATION

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SUMMARY
The focus of this paper is on facilities planning and layout design of a railway station based on pedestrian movement and volume. It is important to ensure efficient passenger flow at stations from entering/leaving the station to departing/arriving at the station. One way of improving the passenger flow is by examining the current facility layout and exploring alternative designs thereof. A good layout of the service facilities in a station can reduce the total walking distance of passengers to and from various facilities. It improves the overall service efficiency and quality of the station.

The assessment of station design by applying a pedestrian flow simulation model, is addressed. In particular, station design issues pertaining to the way the layout and infrastructure items will influence pedestrian flow operations with level of service (LOS) and congestion, were investigated.

Principles and guidelines for railway station design were then explored. From this an acceptance criteria (Fruin’s Levels of Service) were identified with which the appropriateness of different station design components (stairs, walkways, platforms, queuing areas) were evaluated.

A case study of a typical railway station was investigated to explore its current situation. These findings were used as inputs for the simulation model. The assessment of the station’s design was analysed by applying dynamic simulation to model the current situation (Base Year Model) and the future situation (Future Scenario Model).

The Base Year Model was developed to demonstrate the current peak hour operations and pedestrian flows. Critical areas at the station were identified as the stairs at the entrances, the faregate lines and the stairs leading to the busy platform. The data of these critical areas were obtained through SIMIO® simulation and evaluated against the recommended Levels of Service. The model proved the existing layout adequate to handle the current demand.

A Future Scenario Model was developed to test if the critical areas could handle the projected demand. The model showed the existing layout adequate to handle the projected demand except for the south faregate line where large queues were formed by pedestrians trying to exit. It was recommended to add an extra two faregates which resulted in shorter waiting time per passenger.

1.0 INTRODUCTION

To enable planners and designers of railway stations to present an optimal facility, specific principles and guidelines are followed to promote a consistent ‘best practice’ approach in facility planning and layout design of the station. Despite some parts of stations having standardised components, station design is site-specific with no two stations ever being precisely the same. Planners and designers therefore have the freedom to tailor specific outcomes to meet the needs of passengers and services. Because different station types exist, this paper provides general guidelines which can be applied to all stations.

The discussion of these principles and guidelines is divided into two sections:
- principles for station design (functional station design principles);
- considerations for station design (pedestrian characteristics and design guidelines).

Acceptance criteria using Fruin’s Levels of Service [1] can then be identified and used to build simulation models to assist in the planning process.
2.0 FUNCTIONAL STATION DESIGN PRINCIPIES

To ensure that a railway station functions completely, some station design principles need to be considered as described in the TransLink Transit Authority Report [2]. The aim of these principles is to ensure that passenger requirements are fully incorporated into station planning and layout design. The design principles will also ensure that the current station operation demands and future demands are met. For this investigation, the following design principles were used in conjunction with the selection of station layout and arrangements and consideration of capacity limitations as described in a report by NetworkRail [3].

2.1 Functioning Arrangement Of Space

Effective spatial management plays a significant role in the logic and quality of passenger and station visitor movement, supported by subsidiary systems such as station wayfinding and information displays. Consideration should be given to the differing needs of arriving and departing passengers.

Furthermore, railway stations consist of private and public spaces. The public space consists of a “paid” and “unpaid” area, while the private area includes areas such as management and maintenance facilities, electronic cupboards, etc. It is essential that private areas must not obstruct any passenger flow in public areas. The station must therefore be designed in such a way to minimise any pedestrian flow interruptions caused by private areas.

2.2 Passenger Sequence Of Movement

The station layout should allow passenger movement to follow a logical sequence which should respond to their forward movement in the direction of their travel. Passenger flow should be in a forward direction from the entrances to the points of departure, as seen in the following figure.

![Figure 1: Passenger Move Sequence [2]](image)

2.3 Direct, Continuous Movement

The ideal station layout should allow for the most direct path from start to finish and must avoid turns in passenger paths, especially those that constitutes turns of more than 180°. This is graphically shown in figure 2.

![Figure 2: Direct Movement [2]](image)

2.4 Conflict Between Different Flows

Design to minimise potential conflicts between different flows and provide a user-friendly environment. Avoid any cross-flow of passengers. Provision should be made for those moving against the predominant flow. This is shown in the next figure.

![Figure 3: Flow Conflict [2]](image)

2.5 Passenger Density

Personal comfort of passengers plays a significant role in station design. This item is called passenger density. The number of constraints like coming into unwanted contact with other passengers should also be limited. When considering passenger densities, the Levels Of Service (LOS’s) range from LOS A to LOS F where level A is the least crowded environment and Level F the most crowded [1].

It must be noted that different LOS’s are applicable to different station areas. The final design must therefore strive to guarantee comfortable passenger densities in all areas during various peak periods. Fruin’s LOS will therefore be used as a guideline and acceptance criterion to evaluate station system performance by means of simulation modelling.

2.6 Identification Of Entry And Service Points

Members of the public should be able to easily identify a railway station as a place for public transport. Transport facilities should therefore be designed to promote an active street façade. The entrance to the station must be clearly recognisable.
as well as the key areas inside the station (i.e. ticket sale points, fare gates, platforms). In so far as it eases the flow of passengers, signage should be readily visible, easy to understand and simple in design. As far as possible, passengers should be able to interpret the meaning of signage without impeding the normal flow the other passengers around them. An example is shown in figure 4.

![Figure 4: Identification of Signage](image)

Many more principles ensuring a full functioning design are applicable but are not relevant when carrying out a simulation project to study capacities. They are therefore excluded from this paper (principles concerning i.e. visual appearance, maintenance, etc.). The principles listed above are included in the Public Transport Infrastructure Manual intended to provide good practice guidelines for planning and designing public transport infrastructure only.

3.0 PEDESTRIAN CHARACTERISTICS AND DESIGN GUIDELINES

The second set of principles that govern the design of stations, are those that best describe the indigenous characteristics of the major users of the stations. The two main characteristics that will be discussed are the pedestrian speed distribution and the pedestrian spatial requirements.

Limited information on pedestrian behaviour characteristics inside railway stations in South Africa is available. A study conducted by L. Hermant from the Department of Civil Engineering at the University of Stellenbosch [4] is cited in this paper. In his research, observations were made of 24 410 pedestrians at Maatland and Bonteheuwel stations in Cape Town, South Africa. Pedestrian attributes were observed on platforms, stairs and walkways, as well as pedestrian behaviour during boarding and alighting of trains. Local conditions need to be replicated as far as possible during simulation modelling to ensure an accurate representation of the facility under study. Since limited research has been done about conditions at local railway stations, Fruin’s research concerning pedestrian behaviour will additionally be used to fill any gaps presented by Hermant’s research.

3.1 Pedestrian Speed Distribution

The unimpeded speed distributions of South African men and women who are actually going to use the facility under study are discussed. The results presented have been limited to horizontal movement (platforms/walkways) observations only.

- **Effect of Gender:** Men on average walk faster than women with the difference being 1.19m/s compared to 1.01m/s.
- **Effect of pedestrian body size:** An increasing body size causes a decreasing trend in walking speed, both for males as well as females. Typical speeds for males range from 1.49m/s for a lean built male to 1.19m/s for a large built male.
- **Effect of group size:** Single pedestrians walk faster than those walking in groups ranging from 1.2m/s for a singleton to 0.9m/s for group size $\geq 3$. Studies further found that approximately 20% of female passengers walked in groups of 2 or more, compared to 9% of males.
- **Effect of baggage on mobility:** There is a significant difference in the walking speed of pedestrians not carrying baggage to carrying baggage, from 1.4m/s to 1.0m/s. These results are contrary to those of Fruin [1] but collaborate the more recent findings where it was found that pedestrians with baggage have much slower speeds than those without baggage. According to local studies by Hermant [4], approximately 78% of female passengers were found carrying a sling bag or large handbag, compared to 39% of males. Furthermore, 26% of the male population were found carrying nothing compared to less than 2% of females.
- **Different movement types:** Passengers speed tend to differ depending on whether boarding, alighting or waiting for trains. Results show that the walking speeds of boarding passengers on platforms are much faster than those of alighting and waiting passengers. The waiting speed found by L. Hermant [4] is very similar to the data collected by Hoogendoorn and Daamen [5].
- **Speed on stairways:** According to Fruin [1], the ascending speed on stairs is about one-third of the normal walking speed, while the descending speed is about 10% faster than the ascending.
To conclude the discussion on pedestrian speed distribution, and to reduce the subsequent simulation modelling complexity, walking speeds were combined with the speeds proposed by Fruin [1], who recommends a normal walking speed between 0.76 – 1.76 m/s, with an average of 1.37 m/s, see figure 5.

![Figure 5: Normal Walking Speed Distribution](image)

Fruin’s recommended speed is slightly higher than the normal walking speeds proposed by Hermant [4]. However, since the project aims to develop a model of a transport facility during the busiest period, when passengers are in a rush to reach their destinations, Fruin’s suggested walking speeds will be more realistic.

### 3.2 Pedestrian Spatial Requirements

In the early 1970’s, John Fruin developed a transport industry measure for the spatial requirements of pedestrians. This measure refers to the relationship between the density of pedestrians and the speed at which they travel or circulate: these are expressed as ‘Levels of Service’ (LOS). Fruin’s theories were defined around comparing pedestrian flow to fluids and his research has been universally accepted and has become the standards for many facility design and planning operations [3].

The basis for Fruin’s theory has subsequently been challenged by Still [6], whose theories contradicted Fruin’s traditional fluid model of pedestrian flow. However, at lower density crowd levels, Fruin’s LOS remains suitable as a general “rule of thumb” and has formed the basis for evaluating the facility layout in relation to pedestrians as shown by David Associates [7].

Since limited anthropomorphic data of South African citizens are available, Fruin’s data concerning body dimensions are recognised and discussed. Fruin states that: The shoulder breadth and body depth are the main human measurements used in considering pedestrian facilities and spaces. Shoulder breadth plays a major role in the design of stairways, doorways, etc.

According to the Victorian Rail Industry Operators Group Standards 2011 (VRIOGS 002.1) [8], the measurement for an average male is 50cm by 30cm, as shown in figure 6.

![Figure 6: Average Spatial Requirement [6]](image)

This represents a major proportion of the world’s population in the 95th percentile range of anthropomorphic sizes. The plan view of an average male body occupies an area of approximately 0.14m² while unavoidable contact with others begins at an area of 0.21m² per pedestrian.

An individual area of at least 3m² per pedestrian is required for pedestrians to attain normal walking speeds and to avoid conflict with others. At areas smaller than 0.186m² per pedestrian, virtually all movement is stopped (densities above 4.7 pedestrians per m² is considered dangerous). When there’s a large crowd in a confined space, this density can result in shock waves and potentially fatal crowd pressures.

The Fruin data may be too generous as Fruin made his measurements mostly in city street environments in America. The body dimensions presented here are thus considered as representing ideal conditions if the space is available.

Using Fruin’s LOS measures to evaluate station system performance as discussed in VRIOGS [8], the following guidelines can now be proposed:

- **Walkways/Overpasses:** Overpasses primarily function as pedestrian walkways and a LOS C is thus preferred to be achieved during peak periods. Two people walking next to each other require a width of 1.5m to walk comfortably. Since transit facilities can experience heavy two-way traffic flows, a minimum walkway width of 3m must be used. Furthermore, LOS standards are based on the net effective width of the walkway, which requires that
150mm must be added to each edge to account for the avoidance of walls [8].

- Stairway Design: Stairs should comply with the applicable design standards including landings, handrails, the proportion of threads to risers, etc. Stairways in rail applications experience two types of demands during the departure peak and arrival peak. During the departure peak, passenger demands are more uniform throughout the peak period, opposed to the arrival peak when large amounts of passengers can alight from train over very short periods, causing the stairs leading to the station exits to become overloaded and queues to form. Stairs will operate at full capacity (LOS E) during these peak demand periods. Therefore, the LOS should be calculated based on pedestrian flow during the peak hour with pedestrians moving in both ascending and descending directions. Stairways should be designed to LOS C as defined by Fruin [1] to achieve a pedestrian flow rate of 26 passengers/minute.

- Queuing and waiting areas: Queuing regularly occur in rail stations on stairs, ticket issue machines, fare gates, and platforms. The LOS required for waiting in a station facility is a measure of the amount of people waiting, the amount of time spent waiting, and the desired level of comfort. Usually, the longer the waiting time, the greater the space required per person. People will generally not wait for more than 15 minutes (reaching LOS D). The space allowed for queuing should satisfy as a minimum a LOS C.

- Platforms: Railway stations can comprise of two platform layouts: ‘side’ platforms and ‘island’ platforms. The station under study consists of an ‘island’ platform which is a platform serving two train tracks (see case study). A typical island platform can be graded as LOS C.

To conclude this section, it is proposed that the spatial requirements of railway stations are based on the minimum operational capacity determined according to the minimum acceptable LOS. The minimum acceptable Level of Service is LOS C for all station elements.

4.0 CASE STUDY

Using the design guidelines as discussed in section 3, a typical busy station on the main Cape Town corridor was chosen to represent the case study to be modelled and simulated.

4.1 Background To Woodstock Station

Woodstock railway station is the station under study. The study of this station was undertaken at the request of Passenger Rail Agency of South Africa (PRASA). PRASA required an analysis of station design issues pertaining to the way the layout and infrastructure items will influence pedestrian flow. This section presents the current situation at Woodstock railway station by exploring the existing layout and passenger flows. The case study is ultimately used to simulate a Base Model of the station “as-is” during the peak period. Problem areas and facility requirements are then identified.

To support the evidence base for the case study, regular site visits was made to observe the passenger flows and service operations. The observations included in this case study were made during the peak period, identified as 7:00 – 8:00 am on weekdays. Personal interviews with PRASA and Metrorail staff were also conducted to ensure a comprehensive understanding of Woodstock station.

Different types of pedestrians use the Metrorail stations as single passengers or in groups. The usual combination of passengers in a railway station would represent a heterogeneous group, i.e. different socio-economic standing, different trips and motivations for being at the railway station, with no common connection apart from their choice to use that particular station [7].

According to NetworkRail, [3], the different types of pedestrian at any railway station include the following:

- Working class travellers: Include people who are familiar with the station’s layout, usually travel during the peak periods, and choose to spend the minimum time possible in the station.
- Leisure travellers: Include people who rarely use the station, usually travel outside the peak periods, and tend to have longer dwell times than working class travellers/commuters.
- Disabled passengers: Include people who have physical or cognitive impairments which impacts their ability to move within a station environment. These people usually have specific requirements for more space, more time, staff assistance, or step free access.
- Travellers with luggage: Include people who may be restricted in their movement, require more space, and may move more slowly.
- Travellers with children: Include people with slow moving children or children in
prams/pushchairs which may require more space.

Having studied all the collected data on Woodstock Station, the majority of passengers using this station during the peak period were identified as working class travellers, therefore only this type of pedestrian was considered for the project that will form the basis for the simulation project.

4.2 Woodstock Station Layout

Woodstock railway station is located between Porter Street to the north and Grey Street to the south. Two views of the locality plan is shown in Appendix 1.

The platforms are served by trains with 8-cars and average carrying capacity of 1800 passengers. During the am peak hour 32 trains are scheduled to arrive at Woodstock station. Scheduled headways range from 5 to 37 minutes with an average headway of 13 minutes.

Appendix 2 illustrates the peak period train services with reference to the infrastructure of the train tracks. Woodstock railway station allows for boarding and alighting from numerous locations along the station platform.

4.3 Woodstock Passenger Flow

Pedestrian flow at a railway stations are related to station design and movement behaviour of pedestrians. It is therefore mainly a function of arrival capacity and walking speed of pedestrians. It also depends on the status of servers and spatial availability through the walking route.

4.3.1 Ingress flow

Pedestrians can access the station from the north or south building entrances, or from the platforms when arriving by train (alighting passengers). They enter the station from the building entrances either to board trains or to use the Public Street-to-Street Bridge to reach the other side of the station. When entering with the purpose of boarding a train a pedestrian will have to possess a valid train ticket or purchase a ticket.

4.3.2 Egress flow

Pedestrians exit at the building exits when they entered the station with the purpose of getting to the other side by crossing the Street-to-Street Bridge or when they arrived with trains and Woodstock was their final destination. Before the passengers who arrived by trains can exit the station, they need to verify their tickets at either the north or south fare gate. The majority of passengers however exit at the south exit.

5.0 SIMULATION OF CASE STUDY

The simulation model was developed to discover the effects that certain components inside the station have on the flow and volume of pedestrians and passengers. Therefore, different “what-if” scenarios were addressed including:

- Base Year Model: Existing demand – peak period (7:00–8:00 am weekdays)
- Future Scenario Model – future patronage and service growth (2% increase per annum for the next 15 years)

The aim of the modelling process was to evaluate the existing station design to determine if the current layout is effective or needs to be changed. This involved testing not only the normal day to day operations during peak periods, but also ensuring that the existing facility layout would accommodate an increase in patronage over the next few years.

The station was modelled with SIMIO® software as a dynamic, stochastic, discrete-event model using a microscopic approach. The simulation model’s purpose was to analyse the “performance” of Woodstock railway station during different “what-if” scenarios.

The basic concept of the model was controlled by the movement of individual entities (pedestrians/passengers) between key locations over a node network. The position of the nodes in this network was determined by the infrastructure (railway station facility) under study. A 3D model of Woodstock station was imported in the SIMIO® model. This 3D model included all the key areas which were connected by placing nodes in the areas and connecting them with each other. The nodes represent a network intersection, passages (e.g. bridges) or links to processes (e.g. ticket purchase points, ticket verification points). Stairs are special types of nodes with adjusted speeds. Based on the destination and purpose of the pedestrian the nodes have several sequential destinations inside the station.

The pedestrians will have certain walking speeds when moving from one node to the next. This speed was based on the type of movement (horizontal and vertical) in the area and based on guidelines from section 3. Accordingly, each time the pedestrian entered a node, its walking speed was adapted to the type of movement.

5.1 Model Development

The Base and Future Model’s inputs include:

- The number of pedestrian entering and exiting the station and the cycle times at the fare gates and ticket purchase points.
- The number and time of train services and volume of passengers boarding and alighting these trains.
- The pedestrian speed profile and spatial requirements as discussed in section 3.
- The dimensions of the identified critical areas.
Specific assumptions necessary to carry out the simulation.

5.2 Simulation Results

The above inputs were used in the simulation model to measure the density and flow rate of passengers at the critical areas. These outputs were then measured against Fruin’s Levels of Service used as an acceptance criterion (discussed in section 3). Depending on the LOS found for each critical area tested, those areas not within the appropriate LOS range will be studied further and suggestions will be made about possible layout improvements.

A typical simulation result for the Base Year Model is shown in Appendix 3 (North Stairs). In this case, the stairs operate within the required LOC C threshold with only two brief occurrences within the LOS D threshold. The staircase was therefore considered as operating at its operational capacity in terms of the LOS criteria.

For the Future Model, a typical result is shown in Appendix 3 (Fare gates Queue Length).

6.0 CONCLUSIONS

A Base Year Model was developed to demonstrate the current peak hour operations and pedestrian flows at Woodstock Railway Station. Critical areas at the station were identified as the stairs at the entrances, the fare gate lines and the stairs leading to the busiest platform. The performance of these critical areas were obtained using SIMIO® simulation software and evaluated against the recommended Levels of Service. The model proved the existing layout adequate to handle the current demand.

A Future Scenario Model was developed to determine if the critical areas could handle the projected demand. The model showed the existing layout adequate to handle the projected demand except for the south fare gate where large queues were formed by pedestrians trying to exit. In was recommended to add an extra two fare gates which resulted in shorter waiting time per passenger.

The following overall conclusions were made:

- It is possible to use simulation modelling as a method to investigate the performance of a railway station based on given design considerations and guidelines.

7.0 REFERENCES

APPENDIX 1

Figure 7: Aerial view of Woodstock Station [Google Maps]

Figure 8: 3D Layout Of Woodstock Station [Generated by SIMIO®]
Figure 9: Peak Period Train Services At Woodstock Station
APPENDIX 3

Figure 10: Simulation Result For Base Year Model North Stairs [SIMIO®]

Figure 11: Simulation Result For Future Model Fare Gate Queue Length [SIMIO®]