A SIMULATION ANNEALING APPROACH TO DETERMINE THE EFFECTIVE TRAIN STATION LAYOUT WITH DIFFERENT PEAK PERIODS

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ABSTRACT

On daily basis different types of passengers use the Johannesburg commuter rail system. This means that there should be a dynamic and heterogeneous element that should be controlled in the commuter rail system design. A standard approach to designing an effective flow layout is to use From-To-Chart technique from which one can improve on efficiency by minimizing backtracking and then use Block Diagram strategy to obtain the physical display. This has been employed and improvements were achieved in previous study. However, the data that considered was for an overall period. The issue that arises is when the commuter rail system experiences different peak periods and different volumes that sum up to the overall data. If different peak periods and their associated volumes are used to design the layout then the layout will have different efficiencies under the different conditions. This research paper uses the techniques borrowed from simulated annealing to compare different periods and different efficiencies to decide on the layout that is suitable for the commuter rail system under the different peak scenarios. Results shows how flexibility in the layout design can be managed.

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1.1 INTRODUCTION

The United Nations Convention on the Rights of Persons with Disabilities [1], which was ratified by South Africa in November 2007, states that persons with disabilities include those who have long term physical, mental, intellectual or sensory impairments from which interaction with various barriers may hinder their full and effective participation in society on an equal basis with others.

The Passenger Rail Agency of South Africa launched a project [2] whose aims were to identify and address ways of integrating universally accessible designs into PRASA projects. This means that a commuter rail system 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. An approach is to employ modelling and simulation since they play a vital role in the modern life [3] as they mimic the behaviours of the real systems and they are essential in the effective design, evaluation and operation of new systems.

The first simulated annealing was performed by Kirkpatrick et.al [4]. Simulated Annealing is a stochastic optimization technique. Simulated Annealing is a method based on Monte Carlo Simulation to solve challenging combinatorial optimization problems [5]. 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 described 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 $f(s)$[6]. 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 in if facility layout challenges are solved and, furthermore, by also using simulated annealing to develop an efficient layout in a railways system [7]. In this paper the concept of simulated annealing was applied on the From-To-Chart technique, which is the optimization (or cost) function of 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 determined. The solution or cost of the next set of conditions was determined and a decision to move or stay with current solution was based on the efficiency obtained. 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 choosing the route or flow pattern whose total cost is minimized or highly effective layout or route.

At peak conditions, passenger volumes increase at Johannesburg train station. Therefore the rail station needs be designed to serve heavy time based, directional and spatial peaking periods. This paper proposes remedy that will improve passenger flow in a commuter rail system by using simulated annealing applied on From-To-Charts technique as the objective function to determine effective flow pattern that will cater for all the different peak hours that have different efficiencies so that an improved layout that will match the overall expectation is recommended.

1.2 METHODOLOGY

In order to determine the needed facilities in a commuter rail system, Reeds Plant Layout Procedure[8] was followed. By following this procedure information on the type of passengers to be accommodated in a commuter rail system was established, who were children, the elderly, physically limited, auditory limited, inebriated limited, cognitive limited, linguistic limited, pregnant women, temporary limited, visually limited and paraplegics (people on wheelchairs[9]). As reported by Anastasia L. et.al [10], additional differentiating factors are passenger density, passenger attitude and route familiarity. When planning for passenger flow, it is important to take commuter conditions, evacuations, special events, off peak conditions and the types of passenger-flow into consideration as reported by the South Africa Rail Commuter Corporation [11]. That collected data was for the different peak periods per day whose sum gave the overall period data.
From-To-Chart technique [8] was then used to determine the different efficiencies and improve on them by minimizing backtracking, and hence, reducing high penalty points. Backtracking represents the movement of passengers forward and backward within the facility. Backtracking impacts flow by increasing distance moved and its associated cost, thus increasing the penalty point and therefore requires to be minimized. Back tracking values are found in the flow entries below diagonal line that divides the upper right part from the lower left part of the From-To-Chart. The penalty points are obtained by doubling the backtracking entries and then multiplying by the number of cells from diagonal line. Back tracking was minimised by proposing that those cells (i.e. flow between) with high penalty points should be placed closer to each other, and the From-To-Chart techniques applied again to obtain improved routes’ efficiencies. These steps were repeated for all the different scenarios (i.e. different peak periods) and the scenario with the higher efficiency was considered as the preferred layout.

The Block Diagram strategy [8] was used to propose the physical display of the improved train station layout. In order to applying the From-To-Chart technique, all processes or departments where processes take place are listed in the order that is identical to the required flow route across the column and down the row on the left-hand side of the chart. The listing should be in the direction of the overall flow’s layout from beginning to end. Required next was a compilation of process sequence or route for a group of representative passengers. In general, one may consider flow volume, distances travelled, where to, costs etc. The flow of passengers through each process sequence or route was tracked and process chart was completed for each passenger type, followed by performing the From-To-Chart analysis for each data set.

The issue that arose was the fact that the commuter rail system experienced different peak periods and different volumes that summed up to the overall data. If different peak periods and their associated volumes were used to design the layout then there would be different efficiencies under the different conditions.

So, the skill of Simulated Annealing was used to compare the different efficiencies at different peak periods, with the objective of determining an effective facility layout that will accommodate for passengers with special needs. The validation process depended on parameters that need to be matched or compared [12]. The parameters set for this project are the peak periods, passenger volumes, location of facilities and passengers’ flow routes to these facilities at the commuter rail system. As the fundamental concept of simulated annealing comes from statistical mechanics and combinatorial optimization, the layout was improved by occasionally accepting non-improving solutions to allow the algorithm to explore other regions of the solution space instead of just stopping at the first seemingly good solution that was encountered [8]. The data given in Table 1 below was collected for the different peak periods for different passengers. The 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. The ABCDEFG flow route (i.e. a greater major of the customer were 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) was the prescribed route that passengers have to follow in the train station.

A column-by-column combination was considered, and 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 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 occurs at night where less passengers use the train station; however, this period layout will not affect the results obtained for the effective layout as the layout that effectively assists passengers during peak periods will still effectively assists passengers at this time.
### Table 1: A number of passengers at train station

<table>
<thead>
<tr>
<th></th>
<th>06:00am-09:00am</th>
<th>09:00am-12:00midday</th>
<th>12:00midday-03:00pm</th>
<th>03:00pm-06:00pm</th>
<th>06:00pm-09:00pm</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHILDREN</td>
<td>90</td>
<td>68</td>
<td>34</td>
<td>98</td>
<td>10</td>
<td>300</td>
</tr>
<tr>
<td>ELDERLY</td>
<td>150</td>
<td>55</td>
<td>63</td>
<td>182</td>
<td>50</td>
<td>500</td>
</tr>
<tr>
<td>PHYSICAL LIMITED</td>
<td>143</td>
<td>75</td>
<td>53</td>
<td>121</td>
<td>88</td>
<td>480</td>
</tr>
<tr>
<td>COGNITIVE LIMITED</td>
<td>43</td>
<td>91</td>
<td>130</td>
<td>60</td>
<td>26</td>
<td>350</td>
</tr>
<tr>
<td>LINGUISTIC LIMITED</td>
<td>70</td>
<td>40</td>
<td>60</td>
<td>20</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>AUDITORY LIMITED</td>
<td>20</td>
<td>12</td>
<td>32</td>
<td>24</td>
<td>12</td>
<td>100</td>
</tr>
<tr>
<td>VISUALLY LIMITED</td>
<td>20</td>
<td>64</td>
<td>40</td>
<td>15</td>
<td>11</td>
<td>150</td>
</tr>
<tr>
<td>TEMPORARY LIMITED</td>
<td>51</td>
<td>31</td>
<td>44</td>
<td>43</td>
<td>20</td>
<td>189</td>
</tr>
<tr>
<td>PREGNANT PERSONS</td>
<td>40</td>
<td>130</td>
<td>202</td>
<td>86</td>
<td>30</td>
<td>488</td>
</tr>
<tr>
<td>INEBRIATED PERSON</td>
<td>13</td>
<td>50</td>
<td>86</td>
<td>100</td>
<td>151</td>
<td>400</td>
</tr>
<tr>
<td>WHEELCHAIR (PARAPLEGIC)</td>
<td>43</td>
<td>62</td>
<td>82</td>
<td>52</td>
<td>26</td>
<td>260</td>
</tr>
<tr>
<td>ABLED PERSONS</td>
<td>600</td>
<td>200</td>
<td>300</td>
<td>650</td>
<td>200</td>
<td>1950</td>
</tr>
</tbody>
</table>

### 1.3 Analysis of Results

**Scenario 1**

For the first peak period, which was from 06:00am to 09:00am, passenger volumes increased at train stations. In the morning peak, commuters moved with more urgency in order to arrive at work, school etc. in time. During this time what was noticeable with passenger flow was the fact 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 all the times as they relied on their travelling experience. During this period, it was observed that inebriated, auditory and visually limited persons were less at the train station due to crowding since this time could cause discomfort and risks for these people. The From-To-Chart technique whose principle has been explained above was used to measure the effectiveness of the prescribed sequence of flow, which gave 390.5/689.4 = 57% 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.

**Scenario 2**

The second peak period occurred between 09:00am-12:00midday. During this time, it was when 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 are less able passengers who could possibly offer assistance to the abled passengers. However, there are a high number of physical, cognitive and pregnant people during this time at the train station. In this scenario the efficiency of the prescribed route was 66%.

**Scenario 3**

The peak period which was between 12:00midday-03:00pm 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. For children, whose majority was in schools, and the auditory people, whose hearing might be affected by the loud noise, were less in number at the train stations. Under this scenario the efficiency calculated using the From-To-Chart Technique was 71%.
Scenario 4
The fourth peak period, which was from 03:00pm - 6:00pm, passenger volumes increase at train stations. 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 was similar to the first peak period where passengers used the same train station to reach the same destination, day after day and therefore are familiar with their habitual routes. This type of passengers might have not paid attention to their surroundings as they rely 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 may cause discomfort and risks for these people. The effectiveness of the prescribed flow was measured, and it gave 64% efficiency.

Scenario 5
The next peak period occurred between 06:00pm-09:00pm. There were less number of children, linguistic and visually limited people during this period. During this period, it was dark and it might have been a risk for this type of passengers to use the train facilities on their own. The From-To-Chart technique was used to measure the effectiveness of the prescribed sequence of flow, which gave 1673.1/2914.1=57% efficiency.

The overall system efficiency was measured using the From-To-Chart technique for the prescribed sequence of flow and the results obtained was 64% efficiency.

The recommended Efficiency
The efficiencies of the different peak information were compared through deviation analysis were the efficiencies obtained for each peak period, which are 57%, 66%, 71%, 64% and 57%, were compared with the overall 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 efficiency.

1.4 CONCLUSION
The commuter rail system's layout needs to be effective in order to meet passenger’s expectations. Managing passengers’ expectations and improving their train station experience is crucial to the rail business where correlation between passengers and profitability has been widely accepted. Aligning to national imperatives by accommodating for passengers with special needs is important for train stations managers to further explore the train station service quality that will differentiate the success of the commuter rail system. The results that were obtained in this paper illustrate how flexibility in the layout design can be managed. This was achieved through the application of simulation annealing, where different solutions were explored and the From-To-Chart technique where an improved layout was achieved by minimising backtracking. Deviation analysis was employed to determine a cost effective to obtain different layout efficiencies and be able to compare them to a known standard. It is recommended that to redesign the layout of the train station the improved afternoon peak period layout should be used as it matches the overall layout efficiency.

1.5 REFERENCE
[9]. Swart Pieter Project Manager-Park station 24 June.

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