Sustainable Non-Motorized Transport for Ga-Rankuwa and Rosslyn Transport Corridor, City of Tshwane, South Africa

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***Abstract*—A sustainable transportation system is safe, affordable and accessible. It connects different modes of transportation in order to achieve efficient movement. A sustainable transport system is one that is economical and friendly to the environment. All trips in private and public transport begin and end with walking. Non-Motorized Transport (NMT) plays a key role in completion of any journey from origin to destination. However, this mode of transport is not used optimally to enhance sustainable transport, especially where public transport is concerned. The main objective of the research was to evaluate an optimal combination of transport modes for trips made by BMW employees residing in Ga-Rankuwa north of Pretoria, in order to reduce cost of transport. The travel behaviour of BMW employees was investigated by first studying secondary data on the Municipal Household Survey (MHS) and Integrated Transport Plan (ITP) of Tshwane City. The secondary data was supplemented with primary data which was sourced by interviewing the BMW's human resources department and conducting trip studies between Rosslyn and Ga-Rankuwa. The trip pattern of workers of BMW was evaluated to know the origin-destination, journey period and transportation cost of the trips. The movement patterns of the BMW workers were grouped into four categories. The patterns were subjected to optimization using linear programming which included the subsisting movement pattern. The trip patterns developed were based on relevant literature. The BMW workers' movement from home to work was optimized. Their movement to work constituted a transportation challenge or problem; and was solved using simplex technique, a linear programming approach. The model was subjected to a sensitivity analysis and the results were analysed. It was found that the most patronized transportation mode for the trips between Rosslyn and Ga-Rankuwa was taxi. It was further discovered that BMW workers expended R18.47 averagely on movement from home to work through taxis. The recognition of cycling, a means of movement within short distances, allows for additional trip patterns as available options for commuters. The integration of cycling as a feeder system to trains resulted in 36% trip cost reduction for the commuters. The research revealed that while less than 45% of the employees may continue to use the present scenario, more than 55% of the employees may use a combination of cycling and trains. The study suggested that similar work should be done to cover other economic and important routes in order to encourage the use of cycling as a link to other transportation modes in other industrial areas of the City of Tshwane.**

Keywords – sustainable transport; non-motorized transport; origin-destination; simplex technique; travel time.

I. INTRODUCTION

Connection of different modes of transportation is essential for the development of a sustainable transportation system. This will enhance effective, safe and accessible transportation system for road users. Achieving an effective transportation system is challenging in developing countries as the needs of people must be taken into consideration in the design and construction of transportation facilities, even with diverging interest and trip purposes. There is no universally acceptable definition of sustainable transport [1] as quoted by [2]. However, the European Conference of Ministers of Transport (ECMT) in 2004 [3] as quoted by [2], defined sustainable transport as one that is safe, accessible, affordable, and environmentally-friendly.

Non-Motorized Transport (NMT) includes walking, bicycling, skates and wheelchair travel. The non-motorized transport provides recreation and transportation of persons, goods and services. A road user may choose to walk or cycle instead of driving just because he preferred walking or cycling and either is enjoyable to him though it may take more time [2]. According to [4], Non-Motorized Transport affords mobility of persons and goods by means other than automobile combustion engines.

Though users of NMT are many and at different places, they are not considered in the design, construction and improvement of transportation facilities. Physical infrastructures such as overpasses and shoulders are usually not provided for existing NMT users in the upgrade and new development of transportation facilities. The non-integration of NMT facilities in new developments and existing transportation facilities results in high rate of accidents involving automobile and NMT users, delayed travel time and segregation of non-motorized traffic [4]. Despite that NMT modes such as cycling and walking are regarded as sustainable transport modes, their disadvantage is that they are restricted to short journeys [5].

All trips in private and public transport begin and end with walking. NMT plays a key role in the completion of any journey from origin to destination [6]. However, this mode of transport is not used optimally to enhance sustainable transport, especially public transport. The taxi exploits this reality for profits by providing pick-up and drop-off spots as close as possible to passengers' origin and destination points. The rail transportation system is utilized by the public but operates below capacity level because of lesser patronage compared to the taxis. The taxi triumphs over rail because of the perception that rail is the least accessible form of public transport in the City of Tshwane [7].

Many residents of Tshwane have challenges such as high transportation cost and inefficient feeder modes of transport connecting the different types of transportation modes. This is also prevailing in the North Western parts of the City, in areas such as Soshanguvhe, Mabopane and Ga-Rankuwa [8].

An extensive network of rail transportation system is available in the City of Tshwane but is not used to its maximum potential. However, the rail system may be more patronized to enhance accessibility, ease and economy of movement; and effective transportation. Movement to work through public transport is done mainly by taxis, buses and trains. A target set was to ensure that workers spend less than 10% of their income on transportation to and from work. This situation shows that about half (41%) of workers spent more than the stipulated 10% on transportation [7]. A more flexible and cheap mode of transportation is required to enable workers to spend less than 10% of their income on transportation. This research investigated bicycle and walking as the alternative transportation modes to the existing ones. More than half (52%) of the people using train in Tshwane showed dissatisfaction to the long distances between the train stations and their homes [7].

The rail transportation system requires an effective, accessible, comfortable, safe and economical feeder system which would be proximate to homes; time saving; cost effective and more secured than what we have now. This will enhance more patronage, increase the market share obtained through rail services and promote sustainable transportation system [7]. According to [9], low train fares do not only discourage car-owners from using their cars but also divert walkers and cyclists towards train stations.

In order to ensure time and cost minimization when trips are undertaken, the role of NMT as a feeder mode of transport has to be fully comprehended. Full comprehension, optimization and implementation of NMT will result in integration of cycling and walking into other transportation modes which will enhance sustainable transportation system.

The study objective is to determine an optimal combination of transport modes for trips made by BMW employees residing in Ga-Rankuwa, with the aim of reducing transport costs. The investigation of the transportation problem of BMW employees that commute between Rosslyn and Ga-Rankuwa was done to evaluate the effects of integration of cycling into other public transportation means.

II. Methodology

The travel behaviour of BMW workers commuting between Ga-Rankuwa and Rosslyn within the City of Tshwane was investigated. Analyses were done on the information obtained to determine the following:

- Origin-destination;
- Cost of travel;
- Trip duration;
- Travel distance;

The ITP and MHS of Tshwane were used as secondary data to understand the travel patterns of BMW employees. Consultation with human resources department of BMW and the study trips undertaken were used to verify the information obtained from [7]. The study trips were done through taxis, bicycles and trains. Desk study was further conducted using information obtained from secondary data.

The reliability of the information was evaluated based on the source of the information. The information from the study trips and interviews weighed the most and the secondary data from other documents, weighed the least. The evaluation technique used helped in making judgement on the travel behavior, as the data that were collected varied.

Alternative Transport Scenarios

Cycling and walking had been identified as the most dominant forms of NMT by the South African government. Non-motorized transportation has the potential to become a feasible and sustainable mode of transportation [10]. It is projected as a potential mode of sustainable transport. Integration of cycling into public transport such as taxis, bus rapid transit, buses, SARCC Metrorail and Gautrain will result in the development of an alternative transport mode [10].

The alternative transportation mode was developed based on relevant literature as highlighted in Table I.

The following trip patterns were examined:

- Walk for leg 1 to taxi stop, take taxi for leg 2 and 3, and walk leg 4 to BMW Gate 1 (Trip pattern 1 – Status quo).
- Cycle leg 1 to taxi rank, take taxi for leg 2 and walk the final leg to BMW Gate 1 (Trip pattern 2).
- Cycle leg 1 to train station, take train for leg 2 and walk leg 3 to BMW Gate 2 (Trip pattern 3).
- Cycle leg 1 to train station, take train for leg 2 and cycle leg 3 to BMW Gate 2 (Trip pattern 4).

TABLE I. RELEVANT LITERATURE FOR ALTERNATIVE TRANSPORTATION MODES

Materials	Submissions
Tshwane ITP, 2007 [7]	Recommended affordable and reliable feeder transportation modes.
National DoT NMT Policy, 2008 [11]	Recommended guidelines for planning and implementation of NMT infrastructures.
National DoT, 2003 [12]	Proposed design elements of NMT facilities.

Trip pattern 1, which is the status quo, has only one trip with a total duration more than an hour. The one outlying trip is due to travel distance which is in excess of 70 kilometers. Trip pattern 2 has trips from four areas with total duration of travel more than an hour. The areas in question are located more than 10 kilometers away from the taxi rank, therefore resulting in longer cycling time. Hence, the cycling mode is not feasible for the four areas under trip pattern 2. In trip pattern 3, there are six areas with trip duration more than an hour. This is due to longer walking and cycling times. This implies that walking and cycling for those six areas under trip pattern 3 are not feasible. Trip pattern 4 has two areas with their trip duration more than an hour. This implies that cycling is not feasible for the two areas under trip pattern four.

III. TRANSPORTATION OPTIMIZATION

The optimization of transportation cost for BMW workers was approached as a transportation problem. The research was conducted in order to minimize the total cost of transportation by exploring the linear programming approach using the simplex technique method. The problem was solved by building a Microsoft excel model and using a "solver" for the solution. Excel solver is a tool available in excel to solve nonlinear equations, a system of linear / non-linear equations and optimization problems [13]. The model was tested for a number of different trip patterns with their sensitivity analysis results captured and discussed.

Mathematical Formulation

Hypothesize the BMW employees originating from m zones and having n trip patterns to reach their destination. Workers must be transported from their homes to work. Each zone has an s employees residing in it and all employees should use n trip patterns to get to their destinations. The cost of transportation of the different trip patterns is linear. The characteristics of the transportation problem are as follows:

- Total number of workers using trip pattern j for transport is d_j, where $j = 1,2,3...n$
- Total number of workers from unit i is S_i, where $i = 1,2,3...m$
- The travelling time for one employee from origin unit i using trip pattern j *is* Tij, where $i = 1,2,3...m$ *and* $j = 1,2,3...n$. The total travelling time is linear with respect to the distance to be travelled.
- Total transportation cost for one employee from origin unit i using trip pattern j is c_{ij}, where $i = 1,2,3...m$ *and* $j = 1,2,3...n$. The total transportation cost is linear with respect to the number of employees.
- The maximum cycling distance K for scenario j is 5km, where $j = 1,2,3...n$.
- The maximum trip duration *is* Tij for scenario j is 60 minutes, where $i = 1,2,3...m$ *and* where $j = 1,2,3...n$.

$Tij \le 60min$ is a constraint and benchmark set by [7].

$K = 5km$, is a constraint recommended by [14] stating 5 km as the maximum acceptable cycling distance.

Let Z be the total cost and $x_{ij,}$ the number of workers to be moved from source i using trip pattern j, the formulation for this problem gives a linear programing as follows:

$$\text{minimze } Z$$

$$= \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} c_{ij}\, x_{ij} \qquad [1]$$

Dependent on:

$$\sum_{j=1}^{j=n} X_{ij} = S_i, \quad (i = 1 \text{ to } m) \qquad [2]$$

$$\sum_{i=1}^{i=m} X_{ij} = d_j, \quad (j = 1 \text{ to } n) \qquad [3]$$

$$K_j \le 5km, \quad (j = 1 \text{ to } n) \qquad [4]$$

$$Tij \le 60min, \quad (i = 1 \text{ to } m \text{ and } j = 1 \text{ to } n\ ) \qquad [5]$$

and:

$$X_{ij} \ge 0, \quad (i = 1 \text{ to } m\ ; j = 1 \text{ to } n)$$

The Objective Function

The objective function contains costs associated with each function as that of the variables. It is a problem of minimization. Considering transportation from origin unit i using trip pattern j. For any arrangement of i and j, the cost of travelling per worker c_{ij} and the number of workers to be shipped is X_{ij}. Given the hypothesis that there is a linear function for cost, the overall trip cost is $c_{ij}\, x_{ij}$

The sum of all i and j yields the total transportation cost for all origin and trip pattern combinations. The objective function can therefore be as given in equation [1]

The Constrictions

The Constrictions or Constraints are the conditions that ensures demand and supply are fulfilled. A Transportation Problem (TP) has one constraint for each node. The constraints are therefore:

i) Number of workers from all origins that have to be moved:

$$\sum_{j=1}^{j=n} X_{ij} = S_i, \quad (i = 1 \text{ to } m) \qquad [2]$$

ii) Number of workers that should get to the end point:

$$\sum_{i=1}^{i=m} X_{ij} = d_j, \quad (j = 1 \text{ to } n) \qquad [3]$$

iii) Limit for cycling distance K is 5km on any pattern:

$$K_j \le 5km, (j = 1 \text{ to } n) \qquad [4]$$

iv) Total journey time Tij from unit i using trip pattern j should not exceed an hour:

$$Tij \le 60min, \ (i = 1 \text{ to } m \text{ and } j = 1 \text{ to } n\ ) \qquad [5]$$

v) Non negativity:

$$X_{ij} \ge 0, \quad \forall\, i \text{ and } j \qquad [6]$$

An essential and adequate condition for existence of a viability solution to the transportation problem is:

$$\sum_{i=1}^{i=m} S_i = \sum_{j=1}^{j=n} d_j \qquad [7]$$

the implication is that all workers to be moved from each origin must get to their desired destinations.

Formulating the Transportation Problem using Excel

In order to solve a transportation problem, two separate tables were created. The first table was for parameters while the other for the solution. The number of workers from each point of origin was allotted to different trip patterns (Table II).

Five constrictions (constraints) were built-in into the spreadsheet. They are demand; supply; maximum travelling duration; maximum cycling distance and non-negativity constraints.

For supply constraint, total number of worker from each area equaled total number of workers moved through all trip patterns, that is total number of workers between columns C and F equaled total number of workers in column B in the solution table (Table II).

For demand constraint, total number of workers to be moved equaled total number of workers originating from various zones. At the end of row G, a formula (G49 = SUM G30:G48) which calculated total number of workers was inserted to add up the total number of workers moved (Table II).

Cell H49 shows calculated total cost of all trips. The inserted formula calculated the total cost of all corresponding cells in the body of the parameter and solution table. Thus, the formula embedded in cell H49 sums product of cells in the costing worksheet shown in the parameters table and the corresponding cells in the solution table (Table II).

A simplified calculation was done to know if any of the trip patterns would be possible using cycling distance constraint. It was achieved by adding columns of all trip patterns and including cycling one or more of their legs, showing the cycling distances for each scenario and origin (columns E to G, refer to Table III).

TABLE II. DATA FOR TRIP PATTER BETWEEN GA-RANKUWA AND ROSSLYN

	A	B	C	D	E	F	G	H
1		**Parameters Table**						
2			COST					
3								
4	**Source / Origin**	**No. of People / Supply**	**Trip Pattern 1**	**Trip Pattern 1**	**Trip Pattern 1**	**Trip Pattern 1**		
5	Barseba	1	R 49,00	R 16,00	R 10,50	R 12,50		
6	Garankuwa View	3	R 42,00	R 48,00	R 25,50	R 31,50		
7	Garankuwa Zone 1	3	R 42,00	R 48,00	R 25,50	R 31,50		
8	Garankuwa Zone 16	6	R 84,00	R 96,00	R 51,00	R 63,00		
9	Garankuwa Zone 17	1	R 14,00	R 16,00	R 8,50	R 10,50		
10	Garankuwa Zone 2	4	R 56,00	R 64,00	R 34,00	R 42,00		
11	Garankuwa Zone 20	2	R 28,00	R 32,00	R 17,00	R 21,00		
12	Garankuwa Zone 21	2	R 28,00	R 32,00	R 17,00	R 21,00		
13	Garankuwa Zone 25	2	R 28,00	R 32,00	R 17,00	R 21,00		
14	Garankuwa Zone 3	2	R 28,00	R 32,00	R 17,00	R 21,00		
15	Garankuwa Zone 4	2	R 28,00	R 32,00	R 17,00	R 21,00		
16	Garankuwa Zone 5	1	R 14,00	R 16,00	R 8,50	R 10,50		
17	Garankuwa Zone 6	3	R 42,00	R 48,00	R 25,50	R 31,50		
18	Garankuwa Zone 7	8	R 112,00	R 128,00	R 68,00	R 84,00		
19	Garankuwa Zone 8	2	R 28,00	R 32,00	R 17,00	R 21,00		
20	Garankuwa Zone 9	2	R 28,00	R 32,00	R 17,00	R 21,00		
21	Hoekfontein	1	R 14,00	R 16,00	R 8,50	R 10,50		
22	Mmakau	2	R 78,00	R 32,00	R 17,00	R 21,00		
23	Mothutlung	5	R 195,00	R 80,00	R 42,50	R 52,50		
24		**52**						
25		**Solution Table**						
26								
27	DISTRIBUTION OF PEOPLE PER SCENARIO							
28								
29	**Source / Origin**	**No. of People / Supply**	**Trip Pattern 1**	**Trip Pattern 1**	**Trip Pattern 1**	**Trip Pattern 1**	**Total number of people**	**Cost**
30	Barseba	1	0	0	0	0	0	R -
31	Garankuwa View	3	3	0	0	0	3	R 42,00
32	Garankuwa Zone 1	3	0	0	3	0	3	R 25,50
33	Garankuwa Zone 16	6	0	0	6	0	6	R 51,00
34	Garankuwa Zone 17	1	1	0	0	0	1	R 14,00
35	Garankuwa Zone 2	4	0	0	4	0	4	R 34,00
36	Garankuwa Zone 20	2	2	0	0	0	2	R 28,00
37	Garankuwa Zone 21	2	2	0	0	0	2	R 28,00
38	Garankuwa Zone 25	2	2	0	0	0	2	R 28,00
39	Garankuwa Zone 3	2	0	0	2	0	2	R 17,00
40	Garankuwa Zone 4	2	0	0	2	0	2	R 17,00
41	Garankuwa Zone 5	1	0	0	1	0	1	R 8,50
42	Garankuwa Zone 6	3	0	0	3	0	3	R 25,50
43	Garankuwa Zone 7	8	8	0	0	0	8	R 112,00
44	Garankuwa Zone 8	2	2	0	0	0	2	R 28,00
45	Garankuwa Zone 9	2	2	0	0	0	2	R 28,00
46	Hoekfontein	1	0	0	1	0	1	R 8,50
47	Mmakau	2	2	0	0	0	2	R 78,00
48	Mothutlung	5	5	0	0	0	5	R 195,00
49		**52**	**29**	**0**	**22**	**0**	51	R 768,00

Next to columns E to G, additional columns were inserted with a simple formula to determine which trips were viable with a constraint of maximum cycling distance of 5km (columns K to M, refer to Table III). In column K the formula was "IF (G3<5,1,0)", this implies if the distance in cell G3 is less than 5km, then the result should be 1 if not, then it should be 0. The result obtained from k is multiplied by the cells having number of workers from each zone. In solver, the corresponding cell in the solution table must be equal or lesser than the product. Hence, when the trip pattern is impossible, a zero is allotted to cells in the column K to M and the product is also zero would be zero (refer to Table III for ease of reference).

A simplified equation was used to make a determination if any of the trip patterns was possible with the trip duration constraint. It was done by the addition of columns for all trip patterns showing their total trip durations (columns O to R, in Table IV). Next to the columns O to R, other columns were inserted with a simple formula to determine which trips were feasible with a constraint of a certain trip duration. In these columns (columns S to V, in Table IV), a rule was applied. In column S the formula "IF(O3<60,1,0))", implies if the trip time in cell O3 is below one hour, the result would be 1, if not, the result would be 0. The result would be multiplied by the cells containing number of workers from each unit. The corresponding cell in the solution table must not be more than this product. When the option is impossible, zero is allotted to cells in columns S - V and the product of multiplying with zero gives zero (Table IV).

The non-negativity constraint was added via an option in solver that may or may not be selected, by checking a box to *"Make Unconstraint Variables Non-Negative", as* shown in Figure 1.

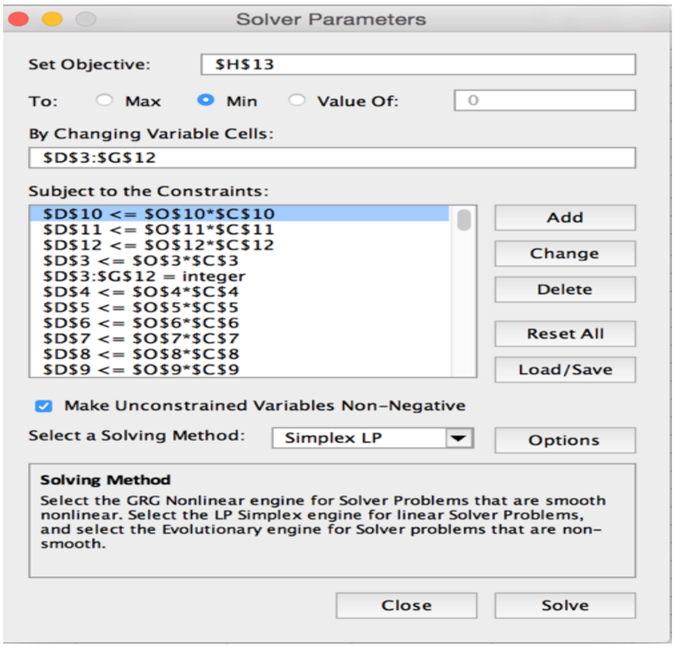

Figure 1: Excel Solver extract for ease of reference

(Non- negativity constraint)

TABLE III. EXTRACT OF CYCLING DISTANCE CONSTRAINT

A	B	C	D	E	F	G	K	L	M
1		CYCLING DISTANCE					5	5	5
2	AREA	No. of People	Trip Pattern 1	Trip Pattern 1	Trip Pattern 1	Trip Pattern 1	Trip Pattern 2 Possible	Trip Pattern 3 Possible	Trip Pattern 4 Possible
3	Barseba	1	n/a	64	35	35	0	0	0
4	Garankuwa View	3	n/a	10,6	10,5	10,5	0	0	0
5	Garankuwa Zone 1	3	n/a	3	1,1	1,1	1	1	1
6	Garankuwa Zone 16	6	n/a	4,7	4,4	4,4	1	1	1
7	Garankuwa Zone 17	1	n/a	6,7	6,6	6,6	0	0	0
8	Garankuwa Zone 2	4	n/a	1,5	2,6	2,6	1	1	1
9	Garankuwa Zone 20	2	n/a	7	6,8	6,8	0	0	0
10	Garankuwa Zone 21	2	n/a	5,8	7,1	7,1	0	0	0
11	Garankuwa Zone 25	2	n/a	7,5	7,4	7,4	0	0	0

TABLE IV. TRIP DURATION DISTANCE CONSTRAINT

	A	B	O	P	Q	R	S	T	U	V
1	ORIGIN AREA	No. of People	TOTAL DURATION (MINUTES)				Trip duration constraint possible? 1=Yes, 0=No			
2			Trip Pattern 1	Trip Pattern 1	Trip Pattern 1	Trip Pattern 1	Trip Pattern 1 Possible	Trip Pattern 2 Possible	Trip Pattern 3 Possible	Trip Pattern 4 Possible
3	Barseba	1	79	276	195	188	0	0	0	0
4	Garankuwa View	3	44	63	72	65	1	0	0	0
5	Garankuwa Zone 1	3	31	32	34	27	1	1	1	1
6	Garankuwa Zone 16	6	35	39	48	40	1	1	1	1
7	Garankuwa Zone 17	1	39	47	56	49	1	1	1	1
8	Garankuwa Zone 2	4	28	26	37	29	1	1	1	1
9	Garankuwa Zone 20	2	39	48	57	50	1	1	1	1
10	Garankuwa Zone 21	2	37	43	58	51	1	1	1	1
11	Garankuwa Zone 25	2	40	50	60	52	1	1	1	1
12	Garankuwa Zone 3	2	32	34	48	41	1	1	1	1
13	Garankuwa Zone 4	2	33	35	44	37	1	1	1	1
14	Garankuwa Zone 5	1	31	31	43	36	1	1	1	1
15	Garankuwa Zone 6	3	29	28	39	31	1	1	1	1
16	Garankuwa Zone 7	8	38	47	61	54	1	1	0	1
17	Garankuwa Zone 8	2	40	49	64	57	1	1	0	1
18	Garankuwa Zone 9	2	39	47	62	54	1	1	0	1
19	Hoekfontein	1	33	37	40	33	1	1	1	1
20	Mmakau	2	48	71	60	53	1	0	0	1
21	Mothutlung	5	50	74	65	58	1	0	0	1
22		52								

The Solver calculations in cell H49 (Table II) were set up to minimize the trip cost, using a simplex linear programming method, by changing variable cells C30 to F48 subject to the constraints as explained earlier. The numerical values of X_{ij} decision variables are contained in cells (C30:F48). The optimized result obtained using the simplex method was calculated in the solution cells and the associated cost is obtained in cell H49 (Table II).

Solver is limited to solving problems with less than 200 variables and 100 constraints, hence the problem was divided into two, but the results were combined to accurately and reliably obtain similar results with Solver in Excel as if the whole dataset were used together (without a split) for all trip origins and trip patterns.

The data that were collected and summarized in Tables V and 6 were utilized for the optimization exercise.

TABLE V. SUMMARY OF DIFFERENT TRIP PATTERNS DATA

Trip pattern	Average Distance	Average Duration	Total Cost
Trip pattern 1	18 km	39 minutes	R 938.00
Trip pattern 2	17 km	57 minutes	R 832.00
Trip pattern 3	20 km	60 minutes	R 444.00
Trip pattern 4	20 km	53 minutes	R 548.00

TABLE VI. TRANSPORTATION DATA FOR WORKERS RESIDING IN GA-RANKUWA

Zone of Origin	Number of Employees	Trip pattern 1		Trip pattern 2		Trip pattern 3		Trip pattern 4	
		**Cost	*Time	**Cost	*Time	**Cost	*Time	**Cost	*Time
Barseba	1	49.00	79	16.00	276	8.50	195	12.5	188
Garankuwa Unit 1	3	14.00	31	16.00	32	6.50	34	10.5	27
Garankuwa Unit 16	6	14.00	35	16.00	39	6.50	48	10.5	40
Garankuwa Unit 17	1	14.00	39	16.00	47	6.50	56	10.5	49
Garankuwa Unit 2	4	14.00	28	16.00	26	6.50	37	10.5	29
Garankuwa Unit 20	2	14.00	39	16.00	48	6.50	57	10.5	50
Garankuwa Unit 21	2	14.00	37	16.00	43	6.50	58	10.5	51
Garankuwa Unit 25	2	14.00	40	16.00	50	6.50	60	10.5	52
Garankuwa Unit 3	2	14.00	32	16.00	34	6.50	48	10.5	41
Garankuwa Unit 4	2	14.00	33	16.00	35	6.50	44	10.5	37
Garankuwa Unit 5	1	14.00	31	16.00	31	6.50	43	10.5	36
Garankuwa Unit 6	3	14.00	29	16.00	28	6.50	39	10.5	31
Garankuwa Unit 7	8	14.00	38	16.00	47	6.50	61	10.5	54
Garankuwa Unit 8	2	14.00	40	16.00	49	6.50	64	10.5	57
Garankuwa Unit 9	2	14.00	39	16.00	47	6.50	62	10.5	54
Garankuwa View	3	14.00	44	16.00	63	6.50	72	10.5	65
Hoekfontein	1	14.00	33	16.00	37	6.50	40	10.5	33
Mmakau	2	39.00	48	16.00	71	6.50	60	10.5	53
Mothutlung	5	39.00	50	16.00	74	6.50	65	10.5	58
***TOTAL	52	938.00		832.00		444.00		548.00	

* Duration is in minutes
** Cost is in South African Rands and it is cost per person
*** Total cost for all 52 employees

Table VI shows that the total cost for the existing single trip of all BMW workers resident in Ga-Rankuwa and its environs is R938.00. Trip patterns 1, 2 and 3 cost R832, R444.00 and R548.00 respectively. The objective was to determine the best trip patterns or combination of patterns for all BMW workers to ensure safety and economy.

TABLE VII. RESULTS OF THE SENSITIVITY ANALYSIS

Constraints (minutes and kilometers)	Total number of workers	TP 1	TP 2	TP 3	TP 4	COST
80 min. & 2.5 km	52	35	0	10	7	R 683.50
80 min. & 5.0 km	52	23	0	29	0	R 603.50
80 min. & 7.5 km	52	16	0	36	0	R 565.00
60 min. & 2.5 km	51	41	0	3	7	R 848.00
60 min. & 5.0 km	51	29	0	22	0	R 768.00
60 min. & 7.5 km	51	15	0	29	7	R 530.00

An optimal solution was obtained using solver in excel. The solution was for 29 workers to continue using the current trip pattern of using taxis to get to work while 22 people would use trip pattern 3 of cycling to the nearest train station, joining train and walking the last 1200 meters to their office in Rosslyn. The original trip cost of R938 between Rosslyn and Ga-Rankuwa has been cut or reduced to R768 by 18%.

Following the detailed analysis, the 60-minute constraint cannot be satisfied by any of the trip patterns because of long distance from Barseba. The existing trip duration for Barseba is 79 minutes, hence increasing the trip duration to 80 minutes satisfies all requirements. Other trip durations are lesser than an hour using at least one of the possible trip patterns. The optimized solution was to keep the maximum cycling distance at 5km and increase the trip duration to 80 minutes. The result gave 23 workers moving via trip pattern 1, 29 workers via trip pattern 3 and only one trip will have a duration more than 60 minutes.

Adjusting time and cycling distance constrictions will allow for further optimization of the result. When cycling distances are halved, the cost increases by 10%. The increase is largely due to cycling being viable only to 10 people as opposed to 22, where the cycling distance is 5 km. However, when cycling distance are increased by 50% to 7.5 km, the cost reduces by 31%. The discount is largely due to cycling being viable to 36 people as opposed to 22, where the cycling distance is 5 km.

Table VII shows the results of the sensitivity analysis that was conducted by reducing and increasing cycling distance and time constraints.

IV. RESULTS AND DISCUSSION

Average trip distances and durations are 18km and 39 minutes respectively, whilst the average trip cost R18.47.

The taxi trip was 35 minutes long and costs R14.00. The trip that was undertaken using a combination of cycling and train services was 33 minutes long and costs of R16.50. Train services charge an extra R10.00 for taking a bicycle into the train, this therefore increases the trip cost. The average distance travelled was 15km for both trips. The optimal solution costs R603.50 which is 36% discounted when compared to the current cost of R 938.00. This implies that the use of NMT as a feeder mode leads to reduced transportation costs. Moreover, when the acceptable cycling distance is increased, the cost of transport is reduced.

In other words, when cycling becomes a viable option to more people, the result would be cheaper transport costs and sustainable transport system. Rahul and Verma [15] had similar findings, where they expressed NMTs contribution to sustainability in India, in economic terms. A saving of 2 626 USD per day is made on congestion costs and another saving of 1 145 USD is made on vehicle costs when 1% of motorized trips with distance less than 5 kilometers dumps transportation through buses and taxis for cycling or walking.

The best solution is that 56% of the commuters should make use of trip pattern 3 and 44% should continue travelling using trip pattern 1 as shown in Figure 2. The different trip durations for the different trip patterns are presented in Table VI. Table 6 also shows the different trip costs for the different trip patterns. Trip costs consist costs of different legs of the trip. Table VI shows higher trip costs for trip patterns 1 and 2 but lesser trip costs for patterns 3 and 4. It can be noted that longer distances cost more than shorter ones. This was evident in the trip from Barseba to Rosslyn with higher cost than other areas within the Tshwane region studied.

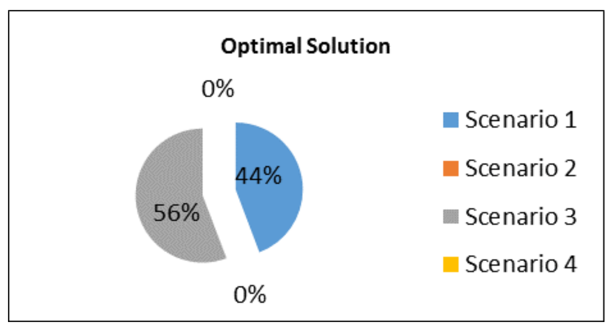

Figure 2: Optimal Solution

V. CONCLUSION

Non-motorized transport as feeder mode of transport opens up opportunities for transportation means other than the automobile combustion engine. Three additional trip patterns were developed as a result of the introduction of NMT as a feeder mode of transport to taxis, buses and trains. The one-hour trip duration constraint was not satisfied in the optimization exercise because trip from Barseba to Rosslyn is more than 70 km. The best solution to the transportation problem is such that 29 employees shift to using trip pattern 3 for their work trips, whilst 23 continue using trip pattern 1. The cost of the trip was reduced by 36% when trip pattern 3 is compared with trip pattern 1, which is the subsisting practice.

The results of the study indicate that when cycling becomes a viable option to more people, it results in cheaper transport cost and enhances sustainable transport. The study recommends that similar study should be undertaken on a wider scale to broaden knowledge and widen horizon on the impacts of cycling, a non-motorized transport mode, as a feeder mode for transportation in other industrial areas of Tshwane and beyond.

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