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Integration of Non-Motorized Transportation to Rosslyn and Ga-Rankuwa Corridor of Tshwane, South Africa

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Abstract: The requirements of sustainable transportation system are safety, affordability, accessibility and convenience. A sustainable transportation system connects various transport modes to enhance efficient movement. It is environmentally friendly and economical. The non-motorized transportation (NMT) may offer safe, efficient, economical and sustainable movements required if integrated with the transportation system. Walking begins and ends trips taken by public and private transportation means. The origin and destination of a journey cannot be completed except NMT is employed. However, NMT as a mode of transportation is yet to be adequately utilized to achieve sustainable transportation in the city of Tshwane. The main aim of this research is to determine the optimal transportation means by integrating NMT into the journey between Ga-Rankuwa and Rosslyn. The travel pattern obtained from trip studies of BMW staff between Rosslyn and Ga-Rankuwa was studied and juxtaposed with the integrated transport plan (ITP) and municipal housing survey (MHS) of Tshwane. A linear programming method called simplex technique was utilized for the determination of trip duration and trip cost from the origin-destination study results. The movement records of the BMW staff was optimized. A sensitivity analysis was conducted on the model and the results were evaluated. The result showed that taxi was the most patronized mode of transportation by the BMW staff between Rosslyn and Ga-Rankuwa corridors. The result also showed that the average trip cost of BMW workers from home to office is R18.47. Integration of cycling as a mode of transportation for short distance trips created 3 more trip patterns. When cycling was integrated to the rail transportation, 36% of the transportation cost was reduced. This work also showed that the subsisting trip method may still be used by less than 45% of the BMW staff while more than 55% of the staff may utilize the integration of cycling and train from home to office and vice versa. This research recommends that similar investigation should be done to other routes of economic importance in the City of Tshwane in order to encourage the integration of cycling into transportation from one place to another.

Keywords: Origin-destination study, simplex technique, sustainable transportation, trip duration, trip cost.

1. Introduction

Development of a sustainable transportation system requires integration of various modes of transportation in order to achieve accessible, effective, safe and convenient movements of road users. Victoria Transport Policy Institute (2012) quoted (Beatley, 1995) that there is no specific definition of sustainable transportation as trip purposes and modes of travel are usually not the same. It is very difficult to achieve effective transportation in a developing country because the various needs of the people should be considered in the planning, design and construction of transportation facilities. The European Conference of Ministers of Transport (ECMT) in 2004 defined sustainable transport as a transportation system that is affordable, accessible, environmental friendly and safe (Victoria Transport Policy Institute, 2012).

Examples of non-motorized transport (NMT) are bicycling, walking, wheel chair travel, and skating. Non-motorized transport serves both recreational and transportation purposes. It facilitates the movements of persons and goods. It is a matter of choice for a person to cycle or walk instead of driving, depending on what the interest or choice of the person is. The man may enjoy cycling or walking but detest driving in order to do exercise, not minding the stress or longer time required (Victoria Transport Policy Institute, 2012). Non-motorized transport enhances movement of people and goods through other means apart from using vehicles on the road (Guitink, Holste, & Lebo, 1994).

There is a high number of NMT users across several places but they are not considered in the planning, design and construction of new transportation facilities or improvement of existing ones. There is usually no provision or consideration for NMT in the development of facilities like kerbs, shoulders and overpasses; or rehabilitation of existing transportation corridors. High accident rate, segregation of non-motorized traffic and delayed travel time result from non-integration of NMT in new facilities or rehabilitation of existing ones (Guitink, Holste, & Lebo, 1994). Though non-motorized transportation like walking and cycling are sustainable, their application may be limited to only short journeys (Ison & Ryley, 2007).

Many trips by public and private transport start and end with walking. Non-motorized transport is essential for the completion of trips from the commencement to the end (Unep Transport Unit, 2004). It is yet to be adequately utilized to achieve efficient and sustainable transportation system in the public transport sector. Taxi motorists utilize this opportunity to maximize their profits, as they pick passengers up and drop them off very close to their residences and destinations. The railway transportation is used by public passengers but its operation is still below its capacity when compared to how passengers patronize the taxi. The taxi is greatly patronized at the expense of the rail because of passenger's mentality that the rail is not as accessible to the public as Taxi in the Tshwane region (City of Tshwane, 2007).

Tshwane residents are confronted with challenges of expensive transportation cost and inadequate feeder modes to connect the different types of transportation means. The experience of residents of North West part, in Mabopane, Ga-Rankuwa and Soshanguvhe areas is not different (City of Tshwane, 2013).

A comprehensive rail network for the city is available but not fully utilized. If the rail system is fully explored it may make transportation more accessible, easier, efficient and more economical. Many passengers go to work using the taxis, buses and trains. The target was that workers should spend below ten per cent of their salary on return trip to work. The current scenario shows that forty-one per cent of workers spend beyond the recommended ten per cent on transportation (City of Tshwane, 2007). A cheaper or perhaps more flexible transportation mode is needed to ensure that people do not spend up to ten per cent of their salary on transport. It is important to evaluate the possibility of integrating walking and cycling with the existing transportation scenarios. Many passengers (52%) showed displeasure over using train, as there is usually a very long distance to cover between the train station and their destinations, homes or work places (City of Tshwane, 2007).

The current challenges of the rail transportation are unavailability of accessible, comfortable, economical, effective and safe feeder system which would be closer to residences in order to enhance security; and save time and money. If the situation is improved, more passengers will patronize the rail system and there will be increased shares obtained from rail transportation system in addition to the achievement of a better and sustainable transportation system (City of Tshwane, 2007). According to Tirachini & Hensher, (2012) when the rail transportation fare is low, car owners are discouraged from using their cars while cyclists and walkers are directed towards the railway system.

Adequate knowledge of non-motorized transportation is required in order to enhance reduction of time and cost of travel. Full understanding of NMT will enhance implementation of optimized transportation resulting from integration of NMT (walking and cycling) with the taxi, bus and train.

The aim of this research was to investigate an optimized integration of transportation modes for trips between Rosslyn and Ga-Rankuwa by BMW workers in order to reduce time and cost of travel. The effects of integrating walking and cycling into the public transportation was evaluated.

2. Methodology

The trip patterns of BMW employees transiting from Rosslyn to Ga-Rankuwa in Tshwane was studied. The results obtained from the origin-destination study were analyzed to obtain the following:

- Origin-Destination
- Trip duration
- Cost of travel and
- Travel distance.

The MHS and ITP records of Tshwane obtained were used to study the travel behaviours of BMW workers. Records obtained from the BMW's department of human resources in addition to results of trips undertaken by the workers were compared with data obtained from City of Tshwane, (2007). Trips undertaken with bicycles, trains and taxis were recorded. The data obtained were analyzed.

The source of secondary information used was adjudged reliable. Primary data obtained from study trip and interview were highly rated. The data obtained varied as the technique used for evaluation assisted in decision making.

Alternative Transport Scenarios

Walking and cycling are the most recognized forms of non-motorized transportation by the government of the Republic of South Africa. Non-motorized transportation is likely to become the practically sustainable and feasible transportation mode in South Africa (City of Johannesburg, 2009).

Non-motorized transportation was projected as the potential mode of transportation. An alternative means of transportation will be developed if NMT is integrated to existing public transportation modes which include buses, bus rapid transit, Gautrain, taxis and SARCC Metrorail (City of Johannesburg, 2009).

Table 1 shows related literature used to develop the alternative modes of transportation. The trip patterns used are as follows:

- TRIP PATTERN 1: Walk to taxi stop; board taxi to taxi rank; board taxi to taxi stop close to BMW; walk to BMW gate 1 (Status quo).
- TRIP PATTERN 2: Cycle to taxi rank; transfer from bicycle to taxi; board taxi to taxi stop close to BMW; walk 200 m to BMW gate 1.
- TRIP PATTERN 3: Cycle to nearest rail station; transfer from bicycle to train; board train and alight at Rosslyn rail station; walk to BMW gate 2.
- TRIP PATTERN 4: Cycle to nearest rail station; transfer to train along with bicycle; board train and alight at

Rosslyn rail station; cycle to BMW gate 2.

Relevant literature for alternative transportation modes

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

The subsisting trip pattern (status quo) is trip pattern 1. It contains only a trip and was undertaken in a period of over an hour. The trip has a travel distance of over 70 kilometers. Trip pattern 2 comprises trips from four different areas with duration of over an hour. The areas are located at distances more than 10 kilometers away from the taxi rank hence it has longer cycling time. Therefore, trip pattern 2 is not a feasible mode. Trip pattern 3 consists six areas with trip duration of over an hour due to longer cycling or walking. The implication is that cycling and walking are not feasible for those six areas under trip pattern 3. Trip pattern 4 consist two areas having trip duration of over an hour which implies that cycling is not feasible for the two areas under consideration in trip pattern four.

3. Optimization of Transportation

Optimizing the cost of transportation for BMW employees was identified as a means of solving the transportation problem which has been begging for solution. This work was targeted at minimizing or reducing their transportation cost with the use of simplex technique which is a linear programming method. A model of Microsoft excel which uses a solver was developed to solve the transportation problem. A tool present in excel spreadsheet for the solution of optimization problems, non-linear equations or a system of linear and nonlinear equations is called 'Excel solver' (Arora, 2012). A number of trip patterns and their sensitivity analyses results were used to test the model.

Mathematical Formulation

Hypothesize that BMW workers are coming from an origin *m* zones and they have to cover trip pattern *n* before they can get to their destination. The workers have to be transported from their residences to work place. The workers can be grouped from the zone where they are coming from as *s* number of workers. All the workers must cover certain trip pattern *n* to get to where they are going (destinations). There is a linear relationship for the cost of transportation of the individual trip patterns. The transportation problem has the following characteristics:

- Total number of workers using trip pattern j for transport is d_j, where $j = 1,2,3 \ldots n$

- 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.*

$Tij \leq 60min$ 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:

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

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

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

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

and:

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

The Objective Function

The cost allotted to individual functions of the variables is referred to as objective function. It results from the problem of reducing or minimizing the cost of transportation from an origin point *i* using a trip pattern *j*. In any consideration for i and j, the travel cost of each worker is c_{ij} and the total number of employees to be transported is X_{ij}. Following the above analysis, there is a linear cost function for the overall cost of trips which is $c_{ij}\, x_{ij}$

The summation of the entire i and j results in the overall cost of transportation for the entire combinations of origins and trip patterns. The objective function is represented as shown in equation [1].

The Constrictions

The Constraints or Constrictions can be expressed as conditions that enhances the achievement of demand and supply.

Any given transportation problem (TP) possesses a singular constraint at each node. The constrictions or constraints can hence be expressed as follow:

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

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

Number of workers that should get to the end point:

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

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

$$K_j \leq 5km, (j = 1 \; to \; n) \qquad [4]$$

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

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

Non negativity:

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

An important and sufficient condition for the workable solution to the problem of transportation:

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

This implies that to effectively move all workers successfully from their individual points of origin to their destination point equation [7] apply.

Formulating the Transportation Problem using Excel

Two individual tables were created to solve the problem of transportation. The first one was created to house the parameters while the second one was to display the solution. The total number of employees from each point of origin was allocated to each trip patterns (Table II).

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

For the supply constraint, the total number of employees from the individual areas equaled the total number of employees moved in all trip patterns. This means that the total number of employees between column C and column F equaled the total number of employees in column B which is the solution table (Table II).

For the demand constriction, the total number of employees to be transported equaled the total number of workers who were from different points of origins or different locations. Row G shows at its end the formula (G49 = SUM G30:G48) which was the calculated total number of employees (inserted) added up to the total number of employees transported (Table II).

Cell H49 shows the calculated total cost of the entire trips. The inserted formula as generated gives the overall cost of corresponding cells in the body of the parameter and the table for solution. Hence, the formula programmed in cell H49 adds up the product of the cells in the costing worksheet as presented in the table for parameters and the applicable cells in the table for solution (Table II).

A simple calculation was made to check if any trip pattern would be achievable using the constraint of cycling distance. This was possible through the addition of the columns for all trip patterns and including cycling in one or more of the legs, showing the cycling distances for each trip patterns and origin (columns E to G of 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, was the insertion of extra columns having simple formula for the determination of trips which were viable and having constraint of 5km distance as maximum distance to cycle as shown in columns K to M (Table III). Column K shows the formula "IF (G3<5,1,0)", which simply implies that if the distance in cell G3 is less than 5km, the result is 1, otherwise the result is 0. The output from k is multiplied by the cells with the number of employees from each zone of origin. The solver provides that corresponding cell in the solution table should be equal or lesser than the product. Therefore, if the trip pattern is not possible, a zero is allocated to cells in column K to M and the product is as well equal to zero as shown in Table III.

A simple equation was used to determine whether any among the trip patterns would be possible with the trip duration constraint. This was achieved by adding columns for all the trip patterns and showing their overall trip durations (columns O, P, Q and R in Table IV). Other columns were inserted next to columns O to R with simple formula for the determination of how the trips were in line with the constraint of trip duration. In columns S to V of Table IV, a rule was applied. For column S, the formula "IF(O3<60,1,0))" implies that if the time for the trip in cell O3 is not up to one hour, the result is 1, otherwise the result is 0. The result is then multiplied by the cells which have the number of employees from each unit. The corresponding cell in the table of solution should not exceed the product. When the option is not achievable, zero is allocated to cells in columns S to V and the product of the multiplication of zero with zero equals zero (Table IV).

The non-negativity constriction was added through an option in the solver that may or may not be selected, by checking a box to *"Make Unconstraint Variables Non-Negative", as* reflected in figure 1.

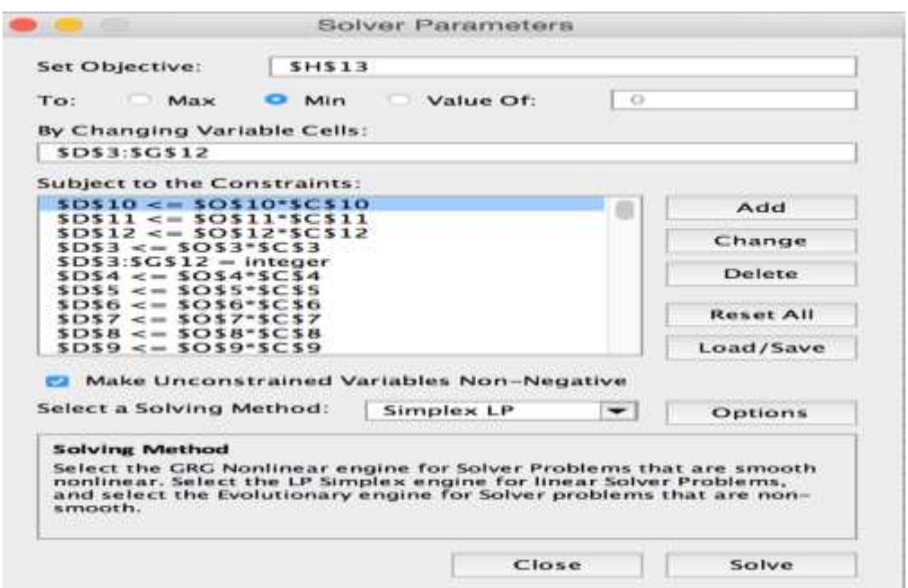

Figure 1: Excel Solver extract for ease of reference (Non- negativity constraint)

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 as contained in cell H49 of Table II were set up to reduce the cost of trip, with the application of simplex technique, a linear programming method, where the changing variable cells C30 to F48 are subjected to the constrictions as expressed earlier. The actual values of X_{ij} decision variables are embedded in the cells (C30:F48). The optimized output obtained from the simplex technique was derived in the solution cells and the associated cost was derived from cell H49 in Table II.

The solver has limitation in solving problems with fewer than 200 variables and 100 constrictions, therefore the problem was separated into two, but the outputs were combined to reliably and accurately get similar results with Solver in the excel spreadsheet as if the whole dataset were used together, without a split for all the trip origins and patterns.

The data collected and summarized in Tables V and VI were used for the optimization of the overall trip costs.

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 Rand and it is cost per person
*** Total cost for all 52 employees

The overall cost of the subsisting single trip of all the employees of BMW residing in Ga-Rankuwa and nearby is R938.00. Trip pattern 1 costs R832, trip pattern 2 costs R444.00 and trip pattern 3 costs R548.00. The study objective was to investigate an optimized integration of transportation modes for trips between Rosslyn and Ga-Rankuwa by BMW workers, in order to reduce the time and cost of travel. The safety and economy of the trip was also taken into consideration.

Table VII: Result of the Sensitivity Analysis

Constraints (minutes and kilometers)	**Total number of workers**	**TP1**	**TP2**	**TP3**	**TP4**	**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 optimized solution was derived with the excel solver. The outcome was that 29 employees will continue to use the subsisting trip pattern (trip pattern 1, using taxis to get to work). 22 employees can use trip pattern 3 which is involves cycling to the nearest rail station; transfer from bicycle to train; boarding train and alighting at Rosslyn rail station and eventually walking to BMW gate 2. Though trip pattern 1 (initial trip) costs R938 to sojourn between Ga-Rankuwa and Rosslyn, trip pattern 3 costs R768 which is a reduction of 18% of the cost for trip pattern 1.

The analysis showed that sixty minute constraint cannot be achieved by all the trip patterns because the trip duration from Barseba to Rosslyn cannot be lesser than 79 minutes. The trip duration was increased to 80 minutes and all the requirements were satisfied though other trip durations were achievable in one hour. The optimized solution was however to maintain a maximum cycling distance of 5km while the trip duration was increased to 80 minutes. This gave an outcome that 23 employees of BMW will be moved using trip pattern 1 while 29 BMW employers will use trip pattern 3.

When trip duration and cycling distance constrictions were adjusted, the optimization of the outcome was achieved. By halving the cycling distances, the trip cost increased by 10%. This increase can greatly be attributed to cycling being viable only to 10 people as against 22, when the cycling distance was 5km. When the cycling distance was increased by half (50%) to give a cycling distance of 7.5 km, the trip cost was reduced by 31%. The reduction was as a result of cycling being applicable to 36 people as against 22 when the cycling distance was 5 km.

The result of the sensitivity analyses conducted to reduce and decrease cycling distance is presented in Table VI.

4. Results and Discussion

The average of the trip distances is 18km, the average of the trip durations is 39 minutes respectively and the average of the trip cost is R18.47.

Moving in taxi for a period of 35 minutes costs R14.00. By undertaking a trip with an integration of cycling and train a cost of R16.50 was incurred for a trip of 33 minutes. There is an extra service charge of R10.00 for taking bicycle into the train. For both trips, an average distance of 15km was travelled. Though the optimal solution has a cost implication of R603.50, the optimization gave a 36% discount when compared with the current cost of R 938.00. The implication is that integration of NMT as feeder mode enhances reduction of the transportation cost. The implication of the use of cycling is that when trip distance increases the cost of travel reduces.

Therefore, implementation of cycling into the transportation scheme is a viable option to many workers as the overall transportation cost will be reduced. In other words, cycling offers a cheaper and sustainable transportation system. This outcome is similar to the findings of Rahul and Verma (2014) that NMT contributed to the sustainability of the transportation system in India. A daily savings of $2,626 was made when cycling or walking was used to cover 1% of the trips, covered by buses and taxis, with distances that are lesser than 5km.

This research offers that the best situation is one where 56% of commuters adopts trip pattern 3 while the remaining 44% commuters continue with trip pattern 1 (Figure 2). Table VI presents the trip duration and the trip cost for each of the trip patterns. The trip cost was inclusive of the cost of the overall legs or divisions of each trip patterns. It can be obtained from table VI that by comparison, trip pattern 1 and trip 2 have higher trip costs but trip pattern 3 and 4 have lesser trip costs. The analysis in table VI also showed that longer trips attract higher cost while shorter trips attracts low cost as Barseba and Rosslyn have higher trip costs than the cost of other locations with shorter distances in Tshwane.

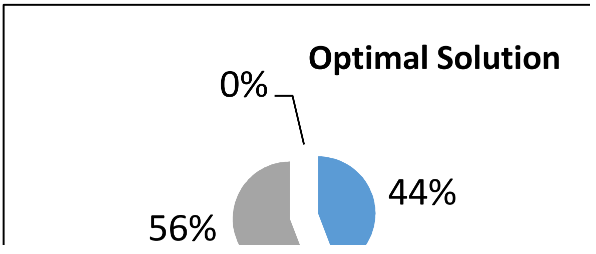

Figure 2: Optimal Solution

5. Conclusion

Integration of the non-motorized transport (NMT) like walking and cycling as feeder mode of transport will open opportunities in the transportation sector as other means of transportation from the combustion of the automobile engines would be used thereby preserving the environment from the danger of climate change. Three other trip patterns were introduced in order to study the effect of the NMT, as a feeder mode, on the trip distance and trip time. The study showed that NMT can be a good alternative for taxis, bus and trains as feeder modes in the transportation sector. The 60 minutes duration constraint cannot be achieved because the trip time for the journey between Barseba and Rosslyn is 79 minutes which is more than the limitation of the time constraint. From the foregoing, the most applicable, acceptable and practical solution to the transportation problem under consideration is that 29 out of the 52 employees make use of trip pattern 3 for daily trip to and from work while 23 out of the 52 employees continue to use trip pattern 1. By the implementation of NMT (walking and bicycling) the trip cost would be reduced by 36%. When the above recommendation of trip pattern 3 is used for the 29 employees, a cheap, environmental friendly and sustainable transportation will be achieved.

This research work showed that implementation of cycling is viable and many people can afford and conform to it because it is a cheaper and sustainable transportation means. It is also recommended that similar work be carried out on a larger scale to improve the transportation system and increase knowledge thereby integrating cycling, a non-motorized transportation mode as a feeder mode for the motorized transportation system in other industrial areas of Tshwane and beyond (Jantjies et al. 2016).

Reference

Arora, J.S. 2012. Chapter 6: Optimum design with excel solver. Introduction to optimum design, 3: 213-273.

Beatley, T. (1995). Planning and Sustainability: The Elements of a New Paradigm. Journal of Planning Literature, 9(4): 383-395.

City of Johannesburg. (2009). Framework for Non-motorized Transport.

City of Tshwane. (2007). Integrated Transport Plan 2006-2011.

City of Tshwane. 2013. Daft 2013/14 IDP Review.

Department of Transport. (2008). Republic of South Africa, Draft National Non-motorized Transport Policy, Dec 2008.

Department of Transport: 2003. Pedestrian and Bicycle Facility Guidelines: Draft.

Department of Transport: 2014. NMT Facility Guidelines: Policy and Legislation, Planning, Design and Operations.

European Conference of Ministers of Transport. (2004). Policy Note and Declaration on Security and Terrorism in the Transport Sector, CEMT/CM (2004)5/Final

Guitink, P., Holste, S. & Lebo, J. (1994). Non-Motorized Transport: Confronting poverty through affordable mobility [online]. Available from: siteresources.worldbank.org/INT URBANTRANSPORT/T-UT-4 [accessed: 28/02/2012].

Ison, S. & Ryley, T. (2007). Options for sustainable mobility. Engineering sustainability, 160 (1), March: 27-33.

Rahul, T.M & Verma, A. 2014. A study of acceptable trip distances using walking and cycling in Banga

Journal of Transport Geography, 38, June: 106-113.

Tirachini, A & Hensher, D.A. (2012). Multimodal Transport Pricing: First Best, Second Best and Extensions to Non-motorized Transport. Transport Reviews, 32 (2): 181-202.

Unep Transport Unit. (2004). Share the Road: Design Guidelines for Non-Motorized Transport in Africa.

Victoria Transport Policy Institute. (2012). TDM Encyclopedia: Evaluating Non-Motorized Transport [online]. Available from: www.vtpi.org/tdm/tdm25.htm [accessed: 08/01/2013].

Jantjies, M., Ndambuki, J.M., Kupolati, K.W., Adeboje, A.O. & Kambole, C. (2016). Reduction of Traffic Congestion and Carbon Emissions through Park and Ride Transportation System. *Proceedings of 3rd International Conference on African Development Issues.* (pp. 275 – 280). CU-ICADI.

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