Determination and ranking of integration measures for land use and transportation applications

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Abstract

The purpose of this paper is to determine the application of weighting and ranking of related and relevant criteria or factors in order to optimise the application of land use and transportation integration goals and objectives on a local municipal (LM) sphere of government in South Africa. For each objective (in the integration of land use and transportation) the utility function will be defined which represents the relative importance of the objective. To integrate, compare and optimise these objective functions that have (in most cases) different scales or units it needs to be normalised or transformed. Weights will be allocated to each criteria or factor that will reflect the importance and thereby the utility of the objective that will be determined. The result of the above mentioned methodology is the creation of a user-friendly scorecard that can be used by local municipalities to audit land use and transportation integration.
Keywords: land use and transportation integration, weight, rank, audit and vector optimisation.

1 Introduction

Vector optimisation also known as multi-objective optimisation is the process used to optimise a set of objective functions refer to Marler and Arora [1] for more technical detail on this method. There is no single global solution for the optimisation problem but a set of points i.e., Pareto optimal set. Koski and Silvennoinen [2] reduce the number of original objective functions by grouping the objective functions into sets i.e. criteria with common characteristics and where the criteria weight is the sum of the weights of the respective criteria's factors. Thus

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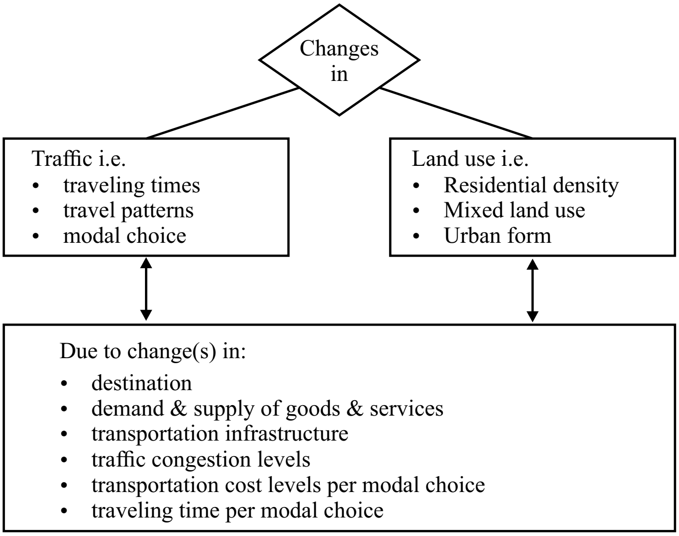

Figure 1: Reasons for changes in traff c and land use
Source: Own construction from [3].

Figure 1: Reasons for changes in traffic and land use. Source: Own construction from [3].

1.1 Overview of legislation and policies

Land use and transportation integration in South Africa is directed and guided by a range of legislation and a range of national, provincial and local municipality (LM) policies and plans exist to further guide and direct land use and transportation integration. These legislation and policies include the Reviewed National Land Transport Strategic Framework (Reviewed NLTSF) [4]; National Development Plan (NDP) [5]; Local Integrated Transportation and Development Plans and Spatial Development Framework [6]; National Land Transport Act 2009 [7] and Spatial Planning and Land Use Management Act 2013 and its Draft Regulation 2015 [8].

2 Methodology

The methodology applied is to use vector optimisation methods to determine how to optimise the identifi ed effi cient solutions (proxies for the effi cient solutions will

the different criteria can be evaluated and measured in terms of different factors (i.e. key features) and thereby the level to which its application and functionality has been achieved can be assessed.

To monitor and evaluate the service delivery and performance of local municipalities an approach towards the development of a scorecard is developed. The development and application of a scorecard inspires continuous assessment and improvement of services to determine the weak and strong points of each local municipality. Thereby, supporting decision making to intervene sooner at local municipalities which perform poor.

The lack of land use and transportation integration in South Africa due to the fragmented urban form lead to problems like commuters who live on the urban fringes which translate to long commuting times and therefore a lost in produtivity. Also, high travel costs (over 70% of South Africans spend at least 30% or more of there income on transport) add to the inability for inhabitants and communities to access economic, leisure and social opportunities.

Figure 1 summarises the interactions between transportation and land use.

1.1 Overview of legislation and policies

Land use and transportation integration in South Africa is directed and guided by a range of legislation and a range of national, provincial and local municipality (LM) policies and plans exist to further guide and direct land use and transportation integration. These legislation and policies include the Reviewed National Land transportation integration is shown in Figure 2. This paper only include steps 1 to 3b).

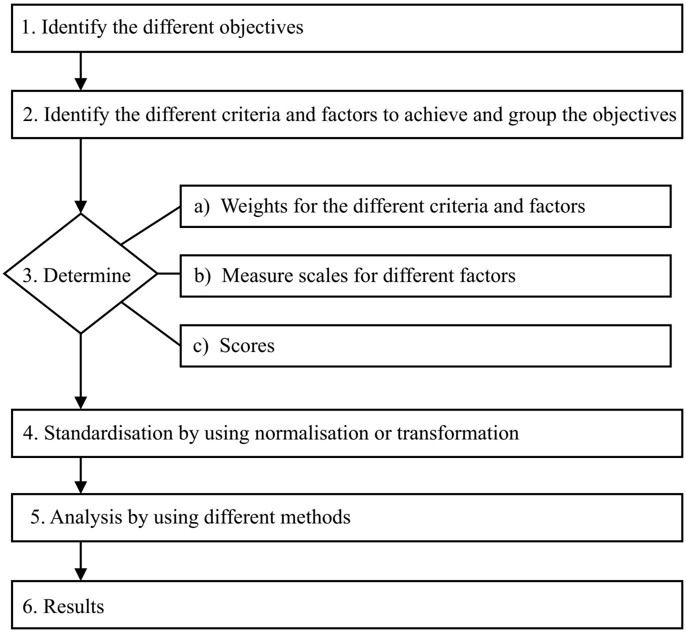

Figure 2: Methodology
Source: Own construction

Figure 2: Methodology. Source: Own construction.

2.1 Alternative options or objectives for the realisation of land use and transportation integration

From legislation and policies [4], [5], [6], [7] and [8] the following alternative objectives for the realisation of land use and transport integration on local municipality level are identified:

1. Densification;
2. Mixed land use activities;
3. The enforcement of land use and traffic policies;

Transport Strategic Framework (Reviewed NLTSF) [4]; National Development Plan (NDP) [5]; Local Integrated Transportation and Development Plans and Spatial Development Framework [6]; National Land Transport Act 2009 [7] and Spatial Planning and Land Use Management Act 2013 and its Draft Regulation 2015 [8].

2 Methodology

The methodology applied is to use vector optimisation methods to determine how to optimise the identified efficient solutions (proxies for the efficient solutions will be the different criteria) which will be used to obtain the milestone of land use and transportation integration is shown in Figure 2. This paper only include steps 1 to 3b).

2.1 Alternative options or objectives for the realisation of land use and transportation integration

From legislation and policies [4–8] the following alternative objectives for the realisation of land use and transport integration on local municipality level are identified

1. densification;
2. mixed land use activities;
3. the enforcement of land use and traffic policies;
4. accessibility;
5. centralised transportation data and land use data and GIS files;
6. mobility.

2.2 Criteria and factors to achieve the objectives

Following and adapting the approach and methodology in (Manual [9]) and (United Nations [10]) to finalise the identified set of criteria and factors each set must be assessed against the following properties: Relationship to the milestone; measurable in a clear and understandable qualitative or quantitative way (therefore determining the measure scales for the qualitative criteria/factors, i.e., nominal (no order); ordinal (order); binary (yes or no) and the quantitative criteria or factors, i.e. interval or a ratio); usable or relevant on local municipality level to land use and transportation integration; data on this criteria or factors must be available; easily obtainable; broad in coverage of all aspects of land use and transportation integration but also mutual independent and of good quality.

By using the policies and plans [4–8] and Litman and Steele [11], Priyanka [12] and Vande Walle *et al*. [13] the following criteria and factors were identified.

(1) For the criteria **density** the following factors were considered

- *Gini concentration ratio (GCR)* of the local municipality.
  The distribution of the urban population in the different residential neighbourhoods in relation to the area. The GCR is calculated as follows

$$GCR = \frac{\sum_{i=1}^{n}(Y_{i+1}X_i) - \sum_{i=1}^{n}(X_{i+1}Y_i)}{10000}$$

$Y_i =$ Cumulative proportion of each residential neighbourhood area;

$X_i =$ Cumulative proportion of each residential neighbourhood population;

$n =$ Total number of residential neighbourhoods in the local municipality.

  The above factor was constructed by adapting the literature on population concentration in countries and provinces to the residential neighbourhoods of a local municipality.
- *Employment-population density* of the local municipality. The proxy for this factor is the Employment rate defined as the proportion of the working-age population that is employed (see Stats SA [14]).

– *Network density (public transport)*

$$\text{Public transport network density} = \frac{\text{Distance of road used by public transport}}{\text{Total road network distance in the LM area}} = \frac{km}{km} = \%$$

– *Network density (bicycle)*

$$\text{Bicycle paths network density} = \frac{\text{Distance of bicycle paths}}{\text{Total road network distance in the LM area}} = \frac{km}{km} = \%$$

– *Network density (quality)*

$$\frac{\text{Demand i.t.o km of road (to be tar or in need of maintenance) in the LM area}}{\text{Total road network distance in the LM area}} = \frac{km}{km} = \%$$

(2) The following factors were used to define the criteria **enforcement of land use and traffic policies**

– *Integration of the three spheres of government (IG).*
First, define a binary value (BV) function as follows

$$BV(X_i) = \begin{cases} 1 & \text{if} \quad X_i = \text{Yes;} \\ 0 & \text{if} \quad X_i = \text{No.} \end{cases}$$

Then the $S_{integration} = \sum_{i=1}^{5} BV(X_i)$ where

X_1 = Linkages in the **planning** between the 3 spheres of government and also the IDP;

X_2 = Linkages in the **projects** between the 3 spheres of government and also the IDP;

X_3 = Linkages in the **budgets** between the 3 spheres of government and also the IDP;

X_4 = Integrated monitoring of **expenditure** on all three spheres of government;

X_5 = Integrated monitoring if programs/projcets are finished **on time and within projected budget.**

Furthermore, the IG factor was classified by considering the value of

$$IGfactor = \begin{cases} \text{Excellent} & \text{if} \quad S_{integration} = 5; \\ \text{Good} & \text{if} \quad S_{integration} = 4; \\ \text{Moderate} & \text{if} \quad S_{integration} = 3; \\ \text{Poor} & \text{if} \quad S_{integration} = 2; \\ \text{Insignificant} & \text{if} \quad S_{integration} = 1. \end{cases}$$

– *Database*

$$S_{database} = \sum_{i=1}^{5} BV(Z_i)$$

for the evaluation of the database on local municipality level the following where considered for the LM database

Z_1 = Consistently updated and accessible for the public;

Z_2 = Integrated database between the different spheres of government;

Z_3 = Contain GIS data on transport network & time series data on transport demand;

Z_4 = Contain GIS and time series data on land use;

Z_5 = Contain GIS and time series data on engineering services.

Furthermore, the range of the rating scale for the Database factor is given the value

$$S_{database} = \begin{cases} \text{Excellent} & \text{if} \quad S_{database} = 5; \\ \text{Good} & \text{if} \quad S_{database} = 4; \\ \text{Moderate} & \text{if} \quad S_{database} = 3; \\ \text{Poor} & \text{if} \quad S_{database} = 2; \\ \text{Insignificant} & \text{if} \quad S_{database} = 1. \end{cases}$$

(3) For the criteria **accessibility** the following factors were considered
- *Travel cost* which is measured as average daily travelling cost (% of income) by category: formally employed and informally employed;
- *Time travelling* = Average travel time per day on public transport;
- *Waiting time* for public transport = Average time per day, waiting for public transport;
- *Public transport usage* $= \frac{Public\ transport\ usage\ in\ LM\ area}{Population\ in\ LM\ area} = \%$
- *Average distance between residential areas and CBD* $:= d($*Res,CBD*$)$. This factor consider the average residential neighbourhood proximity

to CBD.

$$d(Res, CBD) = \begin{cases} \text{Excellent} & \text{if} \quad d(Res, CBD) < 2.5km; \\ \text{Good} & \text{if} \quad d(Res, CBD) \in [2.5km; 5km); \\ \text{Moderate} & \text{if} \quad d(Res, CBD) \in [5km; 7.5km); \\ \text{Poor} & \text{if} \quad d(Res, CBD) \in [7.5km; 10km]; \\ \text{Insignificant} & \text{if} \quad d(Res, CBD) > 10km. \end{cases}$$

– *Average distance between residential neighbourhoods and area of work* $:= d(Res, work)$. Consider the average proximity to work from various residential neighbourhoods.

$$d(Res, work) = \begin{cases} \text{Excellent} & \text{if} \quad d(Res, work) < 2.5km; \\ \text{Good} & \text{if} \quad d(Res, work) \in [2.5km; 5km); \\ \text{Moderate} & \text{if} \quad d(Res, work) \in [5km; 7.5km); \\ \text{Poor} & \text{if} \quad d(Res, work) \in [7.5km; 10km]; \\ \text{Insignificant} & \text{if} \quad d(Res, work) > 10km. \end{cases}$$

These scale intervals for the different factors originate from the Guideline of the Department of Public Service and Administration see [15] but are much more refined.

(4) For the criteria **mobility** consider

– *Average traffic congestion levels*
This was measured by considering the average traffic volumes to capacity (i.e. V/C) ratio.

$$V/C = \begin{cases} \text{Excellent traffic flow} & \text{if} \quad Avg(V/C) < 0.8; \\ \text{Good traffic flow} & \text{if} \quad Avg(V/C) \in [0.8; 0.9); \\ \text{Moderate traffic flow} & \text{if} \quad Avg(V/C) \in [0.9; 0.95); \\ \text{Congestion} & \text{if} \quad Avg(V/C) \in [0.95; 2); \\ \text{Severe traffic congestion} & \text{if} \quad Avg(V/C) \geq 2. \end{cases}$$

– *Forecasted (5-year) traffic congestion value*
This was measured by considering the 5-year forecasted average traffic volumes to capacity (i.e. **E**(V/C)) ratio.

$$\mathbf{E}(V/C) = \begin{cases} \text{Excellent traffic flow} & \text{if} \quad \mathbf{E}(V/C) < 0.8; \\ \text{Good traffic flow} & \text{if} \quad \mathbf{E}(V/C) \in [0.8; 0.9); \\ \text{Moderate traffic flow} & \text{if} \quad \mathbf{E}(V/C) \in [0.9; 0.95); \\ \text{Congestion} & \text{if} \quad \mathbf{E}(V/C) \in [0.95; 2); \\ \text{Severe traffic congestion} & \text{if} \quad \mathbf{E}(V/C) \geq 2. \end{cases}$$

– *Road safety*
This is measured by considering the number of fatalities per 1000 inhabitants in LM area per annum. Note that RSA annum road fatalities $= \frac{0.22\ fatalities}{1000\ inhabitants}$ and Australia's annum road fatalities $< \frac{0.036\ fatalities}{1000\ inhabitants}$ see Iaych *et al.* [16].

$$= \begin{cases} \text{Excellent road safety} & \text{if} \quad \#\ per\ 1000\ inhabitants < \frac{0.036}{1000}; \\ \text{Good road safety} & \text{if} \quad \#\ per\ 1000\ inhabitants \in [\frac{0.036}{1000}; \frac{0.054}{1000}); \\ \text{Moderate road safety} & \text{if} \quad \#\ per\ 1000\ inhabitants \in [\frac{0.054}{1000}; \frac{0.07}{1000}); \\ \text{Poor road safety} & \text{if} \quad \#\ per\ 1000\ inhabitants \in [\frac{0.07}{1000}; \frac{0.18}{1000}); \\ \text{Unsafe roads} & \text{if} \quad \#\ per\ 1000\ inhabitants > \frac{0.18}{1000}. \end{cases}$$

2.3 Determine and normalised of the different (criteria and factors) weights

The ways to determine the different (criteria and factors) weighs can be group in two main categories.

- By physical surveys: Interviews, literature and experts which assess the criteria and factors based on cost and benefits, impact and performance comparisons and thereby order the criteria and factors.
- Calculated and estimated:
  - ∗ Using method of Saaty i.e. eigenvector method (see [17] and [18]) where the first step is to calculate the reciprocal square, (m x m) Analytic Hierarchy Process matrix, A. The matrix A is calculated using $m[m - 1]/2$ pairwise comparison in determining the importance of the different criteria or factors. Furthermore, algebraic manipulation is used to calculate the values for the weights given by the eigenvector, **w** such that $A\mathbf{w} = \lambda_{max}\mathbf{w}$ where λ_{max} is the largest eigenvalue of A;
  - ∗ Logarithmic least squares regression (see De Jong [19] and Laininen and Hämäläinen [20]);
  - ∗ Geometric mean method (GMM) also know as the Approximate eigenvector method or logarithmic least squares method (see Tomashevskii [21]) and many more methods.

Note from [17] that A is perfectly consistent if the weights are exact i.e. $a_{ir}a_{rk} = a_{ik}$. If A is inconsistent then it entails errors Δw_i of the weights, w_i. From [21] follows that ranks of the weights calculated by Saaty method and the Geometric mean method are the same if the error indicator that are used are respectively, the

Table 1: Criteria and factors weights.

Criteria and factor(s)	Weights	Normalised factor weight	Δw_i
1. Density	0.21		0.0091
1.1 Employment-population	0.43	0.09	0.016543194
1.2 Network (public transport)	0.26	0.054	0.016543194
1.3 Network (bicycle)	0.12	0.026	0.016543194
1.4 Network (quality)	0.19	0.040	0.016543194
2. Enforcement of LUT policies	0.15		0.0091
2.1 Integration	0.5	0.075	0
2.2 Database	0.5	0.075	0
3. Accessibility	0.34		0.0091
3.1 Travel cost	0.33	0.112	0.035361216
3.2 Time travelling	0.06	0.020	0.035361216
3.3 Waiting time	0.06	0.019	0.035361216
3.4 Public transport usage	0.21	0.070	0.035361216
3.5 d(Res,CBD)	0.17	0.059	0.035361216
3.6 d(Res,CBD)	0.17	0.059	0.035361216
4. Mobility	0.31		0.0091
4.1 Avg(V/C)	0.38	0.119	0.0304736
4.2 **E**(V/C)	0.35	0.108	0.0304736
4.3 Road safety	0.27	0.083	0.0304736

eigenvector method errors or the GMM errors. In Table 1 the method in [21] was used for the calculation of the weights.

3 Conclusions

In this paper a simplified scientific approach, methodology for application to specific planning instruments such as Integrated Development Plans (IDPs) Integrated Transport Plans and Spatial Development Plans (SDFs) was developed. The methodology developed will promote the integration of transportation and spatial planning and development processes and will improve service and infrastructure delivery within municipalities. This approach has illustrated that planning needs to be managed, focused, reviewed and assessed as to optimise development and delivery, it also unearthed a quantitative and qualitative dimension to service delivery and instrument integration. This support the formulation of performance criteria to improve decision making and management in support of sustainable transportation and land use (spatial) planning.

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