THE AADT-KILOMETRE FORMULA FOR ESTABLISHING BULK-SERVICE CONTRIBUTIONS TO THE PROVISION OF ROAD INFRASTRUCTURE IN URBAN AREAS

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ABSTRACT

Bulk service contributions are often levied by municipal and local authorities responsible for the provision of road infrastructure with the aim of recovering some or all of the cost of the impact of the trips generated on the road network. In South Africa, such contributions are normally established on the basis of the peak-hour trip generation of a development. In this paper, a formula is proposed whereby the developer contribution is calculated based on the AADT-kilometres of trips generated by a development. The bulk service contribution calculated by the formula is therefore in proportion to the overall use of the road network (taking into account peak and off-peak trips).

1. INTRODUCTION

Bulk service contributions are levies imposed on developments with the purpose of compensating an authority for the road infrastructure required (or "consumed") by a development to accommodate traffic generated by the development. Such contributions may be an important source for the funding of road infrastructure.

The purpose of this paper is NOT to address the merits or issues (of which there are many) with bulk service contributions as a funding mechanism. For the purposes of the paper, it is assumed that bulk service contributions are used at least for the partial funding of roads. Given this assumption, the purpose is to evaluate alternative formulae for the calculation of such contributions.

2. PROBLEM STATEMENT

Bulk service contributions have been implemented by various authorities in South Africa and in many other countries. A literature study of instances where bulk service contributions have been implemented, indicated that a range of formulae for the calculation of contributions have been implemented. The formulae may vary from very simple calculations such as multiplying the trip generation of a development with a cost per trip, to formulae based on complex traffic demand modelling.

The following are only a few examples of the different formulae that have been used:

- Transvaal Municipal Association (TMA) formula (Venter Commission, 1984) which determines bulk contribution on the peak-hour trip generation of a development.
- Pretorius and Reeler's (1995) cost apportionment model using travel demand software.

- Traffic Impact Fees are collected in the United States as either *facility based fees* (cost rates determined using road network planning studies) or *needs based fees* which are based on vehicle kilometre travelled (Firtel, 1991; Oliver, 1991; Tindale, 1991).

The question can be raised why such a range of formulae exists? The range indicates that some (or perhaps all) of these formulae may not be adequate for the establishment of bulk service contributions. A formula may either under- or overestimate the extent of the required bulk service contribution and may even assign an unfair proportion of costs to a particular development.

3. EQUITY PRINCIPLE

The equity principle is one of the most important principles underlying the bulk service contribution formula. Based on this principle, the contribution should be related to the cost of road infrastructure required to accommodate road users (or "consumed" by such users).

An important issue with road infrastructure (as for many other services) is that a large portion of the infrastructure is required to accommodate peak hour flow (as for many other types of engineering services). This has resulted in the argument that only developments that generate traffic during the "design hour" should contribute to the cost of road infrastructure.

The problem with this argument is that it would result in certain users paying for the full cost of the infrastructure, while other users would be using the infrastructure for free. Users travelling outside the design hour also benefit from the infrastructure and it would therefore be more equitable if such users also contribute to the cost of such infrastructure, although not to the same extent as users travelling during the peak hours.

The advantage of charging contributions on the basis of peak hour traffic is that a relatively simple formula can be used for the calculation of the contributions. Taking all traffic into account leads to a significant increase in complexity of the formula, although a simplification of the formula is proposed in this paper.

4. CONTRIBUTION FORMULA

There are a number of different bulk services contribution formulae that are used in practice (in South Africa as well as overseas). Oliver (1991) described the following generic formula:

$$\text{Contribution} = \text{Quantity of travel} \times \text{Marginal cost rate} - \text{Credits} \tag{1}$$

The credits granted to a development is a major issue that is a subject of many debates. Credits can be granted for various purposes, such as encouraging economic development in an area or to account for other funding sources available for the provision of road infrastructure. These credits are not further discussed in this paper and only the other factors are considered in the following sections.

5. UNIT OF TRAVEL

The quantity of travel for which developer contributions can be charged can be measured using one of two units of travel:

- Number of trips
- Vehicle - kilometres of travel

Most contribution formulae in South Africa utilise number of trips as a measure of the amount of travel. The problem is that trips alone do not provide a good indication of the amount of road space "consumed" by a development. An example of this is shopping centres. A small shopping centre will generate a relatively high number of trips compared to a large shopping centre (per $100m^2$), but the trip lengths of the large shopping centre is significantly longer than that of small centres. Furthermore, a large proportion of the trips generated by a small centre would be travelling on "internal" roads for which no bulk service contributions are charged. Most of the trips generated by the large shopping centre would be on "external" roads for which bulk service contributions are intended. A formula based on number of trips is therefore unfair to small shopping centres.

Using number of trips as a unit of travel can lead to a significant distortion in the estimation of bulk contributions and in effect means that some types of developments could be "subsidising" other developments. This is not an equitable base for bulk contribution calculations and number of trips is not considered further in this paper.

Vehicle-kilometres is a significantly more equitable basis for the estimation of contributions, although not perfectly equitable. An example of this is the distribution of the cost of the installation of a new traffic signal between developments. In such a case, vehicle-kilometres is not a meaningful measure and number of trips would be a more logical unit of travel. For the purposes of a general bulk services contribution formula, however, vehicle-kilometres is a significantly better unit of travel than trips.

The collection of the vehicle-kilometre data required for different types of developments is not addressed in this paper. However, it is foreseen that this data could by obtained by means of interviews with motorists to determine the trip length to and from the specific development.

6. MARGINAL COST RATE

Most of the current contributions formulae used in South Africa determine the marginal cost rate on the basis of the replacement value of current infrastructure. Many of these formulae are based on the TMA-formula proposed by the Venter Commission in 1984. This formula is currently implemented in cities such as Johannesburg, Pretoria and Tygerberg (CTMM, 2001; Katz, 2003; Tygerberg City, 2003).

The problem with the above approach is that if there is currently an undersupply of road infrastructure, then the marginal cost rate will result in an underestimation of the contribution. The backlog in road infrastructure should be taken into account in the estimation of the cost rate. This can be done through the application of travel demand models, but it is a major exercise that can be highly complex. There are a few examples of this approach in South Africa, but it is not often repeated or applied.

A significantly simpler approach that can be used for the estimation of the cost rate is to simply divide the typical cost of *one kilometre road* by the typical service flow rate during the design hour, expressed in units of *vehicles per hour*. This provides a marginal cost rate that can be expressed in cost per vehicle-kilometre of travel during the design hour.

The cost of one kilometre of a major 4-lane Class 3 road has been estimated as R2 200 000 per kilometre per lane. This cost includes the cost of all services, including the provision of traffic signals, sidewalks, kerbs as well as the cost of land. The cost of land differs significantly, depending on the area in which the land has to be obtained. The cost rate might therefore be higher in areas where the land is very expensive.

The typical service flow rate that can be achieved on one lane of such a road is about 960 vehicles per hour (De Vries 2004). In the peak direction of travel, two lanes of traffic would thus have a service flow rate of 1920 vehicles per hour. Assuming a directional distribution of 60/40, the opposite direction of travel would only have a service flow rate of about 1280 vehicles per hour. The service flow rate in two directions of travel is therefore 3180 vehicles per hour.

Based on this service flow rate, the marginal cost rate can be determined as R2 200 000 divided by 795 vehicles (3180 vehicles/4 lanes), or R2 795 per vehicle-kilometre of travel during the design hour. This cost rate, however, should be adjusted to provide for a distribution of costs between all traffic rather than only trips that occur during the design hour.

In an attempt to simplify the formula, only one cost rate is used for a typical section of roadway. This assumption is considered acceptable, as the cost rates of different classes of higher or municipal roads are comparable (the lower order roads are currently funded directly by developers). The formula could be expanded to apply different cost rates to vehicle kilometres travelled on different classes of roads. However, this would complicate the calculation significantly and would also require more detailed vehicle-kilometre surveys.

7. SIMPLE DISTRIBUTION OF COST BETWEEN ALL HOURS OF TRAVEL

It was previously stated that if costs were only charged for peak-hour travel, it would result in a situation where trips undertaken during other hours would be using the road infrastructure for free, which implies an inequitable distribution of costs between users. An example of this problem can be found in most cities in which most travel during the peak hour is between home and office. Charging costs for travel during the peak hour would result in these trips paying for most of the cost of roads. Developments such as shopping centres that generate most traffic over the weekends (and weekday off-peak periods) would contribute relatively little to roads, although they could attract high volumes of traffic.

To address this problem, an approach can be followed whereby the trips generated during the peak hour of the development rather than the design hour are used. This method leads a significant overestimation of the contribution since it does not account for the "time-sharing" nature of traffic that use the same stretch of road during different hours of the day.

A possible alternative method (which is also not fully equitable) is to simply distribute costs on the basis of the AADT-kilometres (Annual Average Daily Traffic kilometres) generated by a development. For example, assuming that 12% of the AADT-kilometres of travel occur during the design hour, the marginal cost rate can simply be estimated as R335 (12% of R2795) per AADT-kilometre.

The problem with above simple method is that it does not account for the higher infrastructure costs required to accommodate traffic peaking. A method that can be used for this purpose is described in the following section.

8. DISTRIBUTION OF COST BETWEEN ALL HOURS OF TRAVEL

A development that only generates trips during the design hour should contribute proportionally more than other developments that have the same AADT but which generate most trips during other off-peak hours. However, on the other hand such other developments should also contribute to the cost of infrastructure in proportion to the infrastructure actually required to serve the total traffic generated by the developments.

The method of distributing costs between all hours of travel is rather complex and cannot be fully explained in this paper due to limited space. The following is a very short overview of the method and more details can be obtained from De Vries (2004).

The method first determines the portion of the road system required to accommodate a single road user at an acceptable level of service (in units of lane-km). This is a very small portion (or fraction) of the total amount of lane-km available in a city. This small portion of a road is not continually used by this road user over all hours of the year and it is possible to "time-share" this fraction between several road users. The second step in the method is then to estimate the total number of users that can utilise this same portion of the road system. The single road user then contributes to this portion of road infrastructure in proportion to the total number of users that use this portion of the road system.

A user travelling during the off-peak period would be utilising a portion of the road network shared by a relatively large number of users during other off-peak as well as peak periods. On the other hand, however, a user travelling during the peak-period would be utilising a portion of the road network that is only required during the peak hour of each day. Such users would be sharing costs with a fewer number of users than users travelling during the off-peak periods. Their contributions would thus be higher than those of off-peak users.

This concept is illustrated in Figure 1, in which the hours of the study period is ranked from the hour with the highest volume (hour 1) and therefore the highest road infrastructure requirement, to the hour with the lowest volume and therefore the lowest demand for road infrastructure. This is hour 8 in the figure, however, it will be hour 168 if the calculation is based on a typical week.

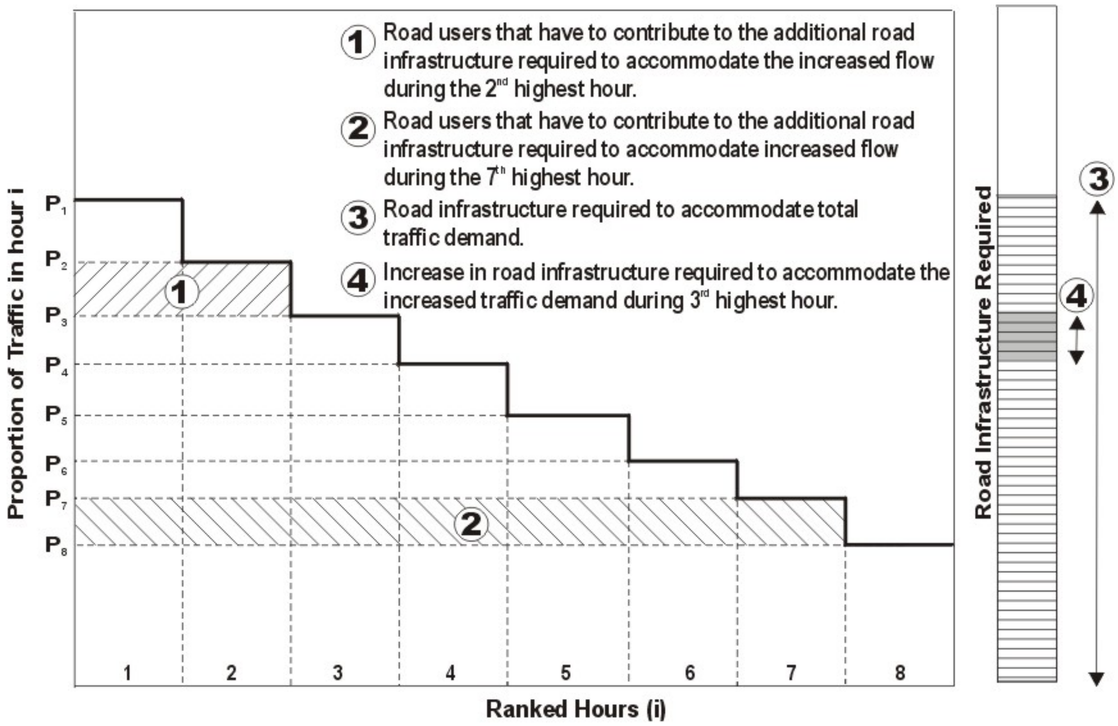

Figure 1. Number of road users that contribute to infrastructure required in each ranked hour.

A specific amount of road infrastructure will be required to accommodate the number of trips in the 7th highest hour, over and above the infrastructure require to accommodate the trips in the 8th highest hour. However, the cost of the additional infrastructure required for the 7th highest hour will be shared amongst all road users in the highest 7 hours (i.e. hour 1 to hour 7). Similarly, the cost of the additional road infrastructure required for the 2nd highest hour, will only be shared amongst the road users travelling during the highest and 2nd highest hours. Developments that generated a large proportion of trips during the peak periods will therefore contribute proportionally more than developments that generate trips during the off-peak periods.

The method, although relatively complex, distributes costs fairly in proportion of the amount of road infrastructure actually required by road users travelling at different hours of the day (or year) but allowing for "time sharing" of the infrastructure. It is therefore an equitable formula that fully accounts for all types of development.

The problem with the method is that it is fairly complex, but not unduly complex. Compared to other engineering calculations such as delays at intersections or bending moments in buildings, the method is in fact rather simple. However, for the purposes of establishing bulk service contributions, this method is probably too time consuming and costly to apply for to each development application.

The method can, however, be used to calculate "peaking adjustment factors" that can be applied to the simplified AADT-kilometre method described in the previous section. Such peaking factors can be determined for different types of developments. Developments that have a peak trip generation during the design hour would have an adjustment factor greater than one while developments that generate trips during other hours would have a factor smaller than one. Additional research is required to quantify these factors for different types of developments, so that these factors can be used to apply the method in practice. De Vries (2004) calculated some preliminary peaking factors for typical development types based on different background traffic flow patterns for different areas (refer to Table 1).

Table 1. Proposed traffic peaking factors f_{dl}.

Development type	Traffic Factor F_{DL}				
	Pretoria	**Centurion**	**Sandton**	**Cape Town**	***Average***
Residential	1.05	1.02	0.97	1.06	*1.02*
School	1.95	1.63	1.23	1.40	*1.55*
Church	0.73	0.71	0.77	0.76	*0.74*
Office	1.08	1.07	1.08	1.09	*1.08*
Retail	0.80	0.84	0.92	0.90	*0.87*
Commercial	1.07	1.04	1.03	1.05	*1.05*
Filling Station	1.01	0.99	0.99	1.02	*1.00*

9. PROPOSED AADT-KM FORMULA WITH ADJUSTMENT FOR PEAKING

De Vries (2004) proposed the formula below to calculate the total developer contribution based on AADT-kilometres. The formula takes all traffic generated by a development into account and allows for the peak nature of traffic as well as the distribution of trips generated in relation to the background traffic flow profile. A detailed discussion of this formula is considered to be beyond the scope of this paper.

$$C_D = AADT_D \cdot L_D \cdot (C_T - C_R) + C_I \qquad (2)$$

in which

C_D = The total contribution to infrastructure by the developer
$AADT_D$ = Annual average daily trip generation of the development;
C_I = Cost of internal services;
C_T = The cost rate (refer to formula below)
C_R = Credit per unit of travel on external services;
L_D = Portion of the average trip length on external roads that should be recovered from the development (km);

The cost rate C_T is estimated as follows:

$$C_T = F_{DL} \cdot F_T \cdot F_D \cdot \frac{C_S}{S_T} \quad (3)$$

in which

F_{DL} = The traffic peaking adjustment factor for a specific development type;
F_T = The proportion of the flow in the highest background hour or design flow of the AADT;
F_D = Factor to allow for the distribution of traffic;
C_S = Cost to accommodate the service flow (cost per unit of travel);
S_T = Service flow rate for the required level of service (vehicles / hour / lane).

De Vries (2004) also proposed that the portion of the trip length that should be taken into account, should be the sum of half the trip length from previous development and half the trip length to the next development. No distinction is made between passer by trips and primary trips, as the fact that a trip is a passer-by trip will be taken into account through the effective shorter trip length for such a trip. This is considered equitable as the passer-by trip derives benefit from the external road network and should therefore contribute proportionally to the cost thereof. An example is a filling station, which would not have been in business where it not for the traffic on a specific section of roadway, but which generates almost only passer-by trips.

An additional factor to account for the impact of heavy vehicles on the road pavement could be included in the contribution formula (De Vries, 2004). Developments would therefore not only contribute based on the road capacity requirements but also based on the impact on the road pavements required to accommodate the trips generated by a development.

10. CONCLUSION

The AADT-kilometre (with adjustment for peaking) formula for the calculation of development contributions has been presented in this paper. This formula accounts for most of the basic principles and requirements for the calculation of contributions. The formula calculates the contribution to road infrastructure based on the average trip length of the trips generated by developments, as well as the annual average daily trip generation of the development (AADT) adjusted to account for the peaking characteristics of developments. The contribution calculated for a specific development using this formula is therefore proportional to the development’s use of the road network during a typical week and not only during peak periods. The AADT-kilometre formula is similar to the formulae used overseas, but is unique in terms of the introduction of the peaking factor. This factor results in the recovery of in a more equitable manner, as it is based on the actual use of the road infrastructure.

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