

Modelling traffic hindrance caused by road construction as part of a multi-criteria assessment framework

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Abstract

One of the consequences of the increased utilization of road infrastructure is more frequent maintenance work. Since generally road works result in less available road capacity, we can witness an increase in traffic hindrance, which involves delays and externalities as noise, air quality, safety and the emission of GHG. Hindrance is generally not restricted to the location where the maintenance works take place, but can occur in a wider area as a result of altered flow patterns in the whole network.

The type of reconstruction, and the way the work is executed determines not only the cost and service life but also the amount of hindrance. We present a multi-objective framework where for a longer period of time, cost and hindrance of specific road maintenance works can be determined, as part of a decision support tool for the optimal planning of maintenance works. For this we developed an alternative traffic assignment method that is able to predict traffic flow in a network in the presence of road works.

Keywords: road maintenance; hindrance; multi-objective; decision support; road construction works

Résumé

L'entretien des routes cause des gênes et de la congestion non seulement sur la zone en travaux ou maintenant, aussi en amont et aval, détériorant aussi la qualité de l'air et augmentant les émissions de CO₂. Le projet présente un outil d'aide à la décision pour la planification optimale des travaux d'entretien. Pour cela nous avons développé une méthode d'affectation du trafic alternative qui est capable de prédire le flux de trafic dans un réseau en présence de travaux routiers.

Mots-clé: l'entretien des routes; entrave; multi-objectif; aide à la décision; construction de routes

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1. Introduction

The use of the road infrastructure has substantially increased during the last decades. As a result road maintenance works must be executed more frequently. Since generally road works result in less available road capacity the impact of road works on delays and externalities as safety, noise, air quality and the emission of GHG is also increasing. This impact is generally called hindrance, which is defined as the objectively measurable externalities induced by road works, while nuisance is defined as the way in which hindrance is perceived.

To create fair competition between contractors, national Dutch authorities implemented the EMAT (Economically Most Advantageous Tender) principle (Dreschler, 2000). This implies that the success of a bid for construction work is determined not only by its cost but also by its quality, which involves the actual improvement of the road pavement, and the amount of hindrance and nuisance. The latter is largely determined by the way in which the work is executed and how it is communicated with all parties involved.

Ideally a successful road maintenance project keeps the balance between all those aspects. It improves the quality of the pavement significantly at a reasonable price and hindrance remains below an acceptable level.

In this paper we present a framework that can help us find the right balance between all these parameters. For a road maintenance project, decisions must be made regarding the type of work, e.g. top layer only or replacing the complete pavement (top layer, binder and base layer), type of execution, such as working hours, e.g. 24/7 or night time only, or blockage (complete or partial) and additional traffic management measures such as a rerouting strategy. All decisions determine the cost of the project, while decisions on type of work determine the service life, and hindrance is mainly determined by type of execution and additional traffic management measures. Obviously external circumstances may implicate that not all combinations are feasible, e.g. when the width of a road is not large enough the combination of partial blockage and complete pavement reconstruction (i.e. top layer, middle layer and base) is not feasible.

2. Framework

The transport network is a public private commodity; it is of high value for society. It is important to properly maintain this commodity, in order to avoid capital loss by poor functionality of the system. The quality of the road network should be kept above a predefined threshold level for supporting safe traffic and transport. This can only be achieved by adequate and timely scheduled road maintenance activities. The starting point for road maintenance works is the quality of the pavement. Most administrations base their strategy for road maintenance on the present state of the pavement (condition based maintenance) and the importance of the pavement within the road network (Burningham & Stankevitch, 2005). The network structure and its robustness are important features when determining a maintenance strategy (Scott et al., 2006). Based on maintenance schemes we can try to restrict traffic obstacles. "Planning" consists of a series of road works, including the time of execution and the pavement materials (e.g. concrete, hot mix asphalt, a combination of those two). These are decision variables in relation to the road maintenance works.

Maintaining infrastructure pavements can be done cyclic or condition based. Cyclic maintenance makes it better possible to plan road works within a network and simultaneously reduce (manage) the hindrance. BB&C studied in 2008 three cases of maintenance at motorways (BB&C, 2008), they found that differences in costs between cyclic maintained pavements and condition based maintained pavements are relatively small. Cuelho et al. (2006) concluded that in the US almost no pavements are maintained "cyclic". Reducing traffic hindrance during road construction works can be done by choosing the most appropriate way of (re-)construction and considering the desired level of throughput of the road link (Brown, 2007). By choosing a specific method of constructing one can tune on the amount of remaining traffic throughput, which also determines the level of service of the remaining traffic flows. Choosing the method of constructing means; deciding on the amount of equipment needed, planning of phases and choosing construction methods, procedures and work hours.

Roadblocks and hindrance are almost unavoidable during road construction. This statement proves that both variables "workspace", "mobility management" and "regulations regarding safety" are strongly interdependent (CROW, 2003).



The framework is a tool that may help in deciding what the best construction measure would be in relation to the traffic situation. It determines what the effects of a specific road maintenance works are, and supports the trade-off between the different effects. Figure 1 shows effects on two criteria (cost and hindrance) that were calculated using the tool, for different solutions of a road maintenance project.

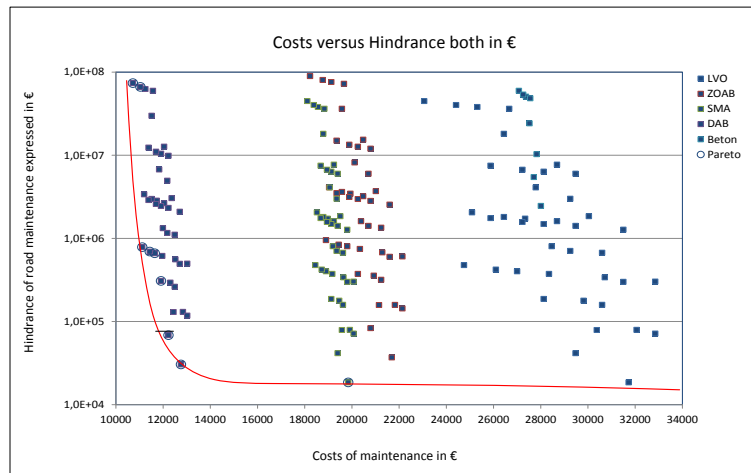


Fig. 1. Different solutions of a road maintenance works with values for cost and hindrance, both expressed in €.

As mentioned before, capacity reduction occurs just along or on the road link under construction. A complete blockage will obviously reduce the capacity to zero, whereas roadwork on the shoulder reduces the road capacity only partially (Rijkswaterstaat, 2002). The use of traffic management measures may affect the capacity of the network both at the location of the road works as well as at other places within the network (Benekohal, 2003).

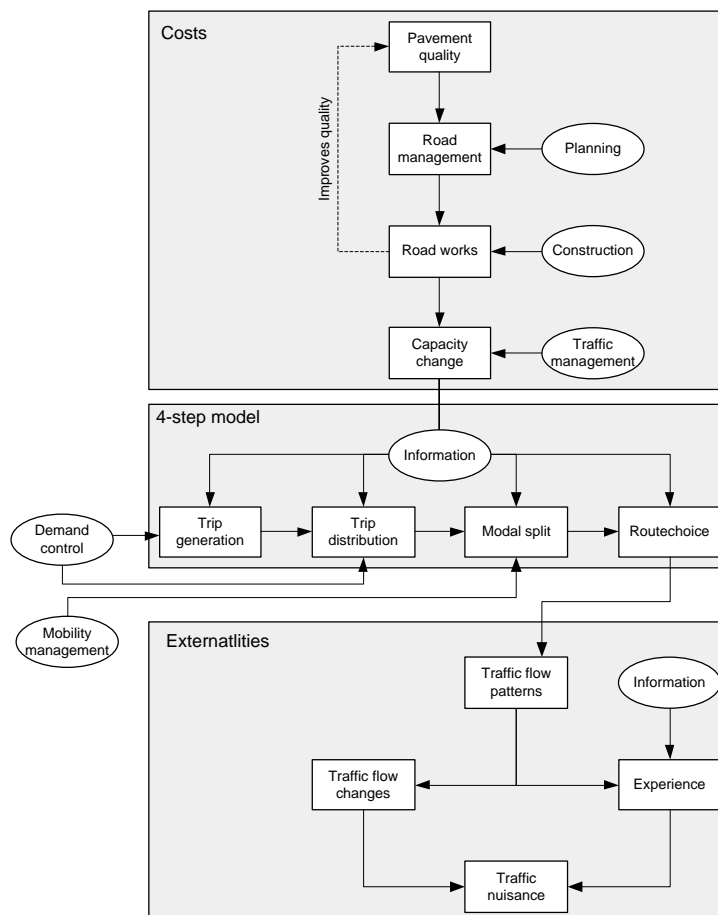


Fig. 2. Framework



In our framework we assume that a maintenance project involves a number of decisions, which in turn result in an altered road network in terms of capacity reductions and traffic management measures. The decisions are listed in table 1.

Table 1. Decisions in a maintenance project

Decision	Possible values
d_1 Construction type	Top layer only, complete reconstruction, i.e. top layer, binder and base layer
d_2 Pavement type	Concrete, hot mix asphalt, ...
d_3 Blockage hours	24/7, daytime, night time, ...
d_4 Blockage type	Partial, complete
d_5 Working zone	Location and size
d_6 Alternative routes	Set of consecutive links for each detour-route

Not all combinations of decisions may be feasible, e.g. in some cases a complete reconstruction may not be combined with a small working zone, or a partial blockage. Further, decisions for construction type, pavement type, type and hours of blockage determine D , the total duration of the project, so $D = D(d_1, d_2, d_3, d_4)$, or more general $D = D(\mathbf{d})$. Then, the construction type and the pavement type determine the service life S of the new road segment, so $S = S(\mathbf{d})$. All decisions imply an altered road network where capacities are time-dependent. For example a project with a complete blockage during night time and no blockage during the rest of the day will result in a network where in the night period the blocked road segments have capacity of 0, where for the other time periods the network remains unchanged. For this a road transport network G is defined as a time-dependent directed weighted graph so $G = G(t) = G(N, L(t))$, where N is the set of nodes, and $L(t)$ is the time dependent set of links. To each link a in the network a travel time function $\tau_a = \tau_a(x_a)$ is assigned, where travel time is assumed to be dependent of the flow x_a and a predefined value of capacity c_a . Often the so-called BPR function is applied $\tau_a(x_a) = \tau_a^0(1 + \alpha(x_a/c_a)^4)$, where τ_a^0 is the free-flow travel time and α is a parameter. Further, in our case we assume capacity to be time dependent so $c_a = c_a(t)$. Obviously, since the network is determined by all decisions it holds that $G = G(\mathbf{d})$.

Now we want to use the altered network, i.e. supply of infrastructure, to determine an altered demand, which in the end results in altered flows in the network. We use these flows to determine new travel times (using the travel time functions τ_a), but also to determine the so-called externalities as safety, emission of GHG, air quality and noise (Wismans et al, 2012). When we compare the current situation in terms of travel times and externalities with the situation that would occur when decisions \mathbf{d} would be implemented, the amount of hindrance can be determined, obviously taking into account duration D and service life S .

To determine the altered demand we use the traditional four-step model, which consists of: trip generation, trip distribution, mode choice and route assignment (Ortuzar and Willumsen, 2001). First the so-called modelling area must be defined. The modelling area usually is a large geographical area, in case of the Netherlands it may be the complete country. The modelling area is subdivided in zones, with for each zone a central point, a so-called centroid. In our case we want to model the effects of road works. As a result, the size of the zones is chosen in such a way that zones near the work area are relatively small, and zones that lie far from the work area are relatively large. The available capacity in the network determines whether an individual makes a trip or not (trip generation), which destination is chosen (trip distribution), which transport mode is chosen (mode choice) and what route is chosen (route choice) (Ortuzar & Willumsen, 2001). The first three steps determine the so-called origin-destination matrix, or OD-matrix, with entries q_{ijt} , indicating the number of trips from origin zone i to destination zone j , departing in time slot t . In the network these trips depart from the centroid of zone i and arrive in the centroid of zone j . The fourth step is also referred to as traffic assignment since not only routes are chosen but also the network is loaded with traffic, where cars are assigned to the chosen routes. When the transport system is at equilibrium (no road works/blocks) it is assumed that no traveller does have advantage by unilaterally changing his or her route. However when construction works are taking place, the way how travellers respond, and, as a result, the way the situation on the network will change, depends largely on the



impact the work has on capacities in the network (Brög & Schädler, 1999) and on additional traffic measures, such as a rerouting strategy.

To conclude, we have developed a framework where decisions on route maintenance are captured in a decision vector d , which includes decisions on the type of construction and pavement, the type and duration of the blockage (e.g. percentage of remaining road capacity), and additional traffic measures. Then for each d total cost and total hindrance are determined, considering not only the area where maintenance work takes place, but the whole network. Now this framework can be used to determine the impact on cost and hindrance of a maintenance strategy that consists of a series of decisions for all road segments in a network over a longer period of time, e.g. 20-30 years.

We argue that not always the best option in terms of cost and quality for maintenance work is chosen, mainly because it is not always clear what the criteria and values for quality are. Our framework can support making those decisions since it is capable of providing these values for quality in terms of delays and externalities. Traditionally in pavement maintenance planning road authorities often only take direct cost into account. Effects fuel consumption; travel times and hindrance are often not accounted for.

Yu and Li (2013) were, among others, early in including these indirect cost in the road maintenance planning process. They also included delays and pollution into their assessment framework. Their approach is based on integration of the life cycle assessment (LCA) model and life cycle cost analysis (LCCA) model in order to optimize the pavement maintenance schedule in terms of energy consumption, the emission of GHG's or cost. However their approach is mainly restricted to the area where the reconstruction work takes place. Our approach is more focussed on a wider area since network effects as a result of changes in route choice may not be restricted to the local area. Then, since in the end we perform a pareto analysis we are able to determine the trade-off between the several objectives. An example is the potential outcome that a reduction of $x\%$ of the emission of GHG implies a cost increase of $y\%$. It is then the task of the road authority to select the best decision, based on a.o. these type of observations.

3. Route choice during road works

The equilibrium situation as defined in the previous section may be valid in regular conditions, but when network maintenance work takes place, which is a clear disturbance of the regular situation this may no longer hold. Generally road authorities install temporal road signs to indicate an officially preferred detour route. Hermelink (2011) has shown that a traditional traffic assignment approach is not always able to correctly describe traffic patterns during road works. He concluded that traffic flows over local detours routes are generally overestimated, while traffic flows on the officially (signed) detours are generally underestimated. To overcome these problems we developed an alternative traffic assignment approach.

3.1. Traditional traffic assignment

Route choice in a traditional traffic assignment is based on the notion that every road user will try to minimize his (or hers) travel cost. This travel cost is composed of travel time, but also distance and costs (for instance toll fees) can be part of this generalized cost equation. In order to minimize its generalized travel cost (GTC) a road user is constantly looking for alternative, more economic routes. Although in practice this behaviour is not so pliable, road users are not constantly checking the alternative routes, in the long run road users will distribute over the various alternative routes. After all, when road users are queuing at the same intersection every day, they either will look for faster alternatives, or accept the queue because they cannot find suitable alternatives.

A very important assumption in this 'user equilibrium' behaviour is that every road user has full knowledge of the road network. This assumption does not only entail that road users know each and every road, it also implies that road users know exactly how busy these roads are, and what corresponding travel times are. The assumption of knowing all roads is already questionable, but could, given the abundant availability of maps and route planners, be given the benefit of the doubt. It is, however, highly unlikely that road users are indeed familiar with the traffic flows and travel times on all roads. In normal traffic simulation, the effects of these assumptions are only marginal. Some road users are more familiar in region a , whereas others know all the roads in region b . And, over time, road users will experience how busy traffic is on particular routes, thereby gathering knowledge on the, for them, relevant part of the road network. Using this information, each road user will eventually find the best alternative and equilibrium is found.



However, during road maintenance road users do not have the time to gather all this knowledge and then move into equilibrium. Road users are suddenly confronted with a closed (or partially closed) road and may have to find immediate alternatives. To aid road users in their decision, road managers often provide signed detours. These detours are usually not the shortest routes (in terms of GTC) and traditional traffic assignment algorithms are therefore unable to estimate the traffic patterns correctly.

3.2. Alternative traffic assignment

Drawbacks of traditional traffic assignment force us to develop an alternative approach that abandons the assumption of road users with full knowledge. Consequently, it is not longer possible to assign all traffic simultaneously and distinctions between groups of road users have to be made.

The most obvious distinction that can be made is based on the familiarity of road users with a specific area. Road users that are familiar in an area will tend to use all types of roads, including the local detours, whereas road users that are unfamiliar are likely to avoid residential and rural roads. Therefore a project area is defined. It comprises of the road works sections, the signed detours, and the surrounding roads, that are expected to be directly affected by the road works in terms of rerouting. Obviously the project area is part of the total modelling area. Within this project area, each type of road users is presented its own unique road network, whereas outside the project area the assumption of full knowledge is maintained. This ensures that outside the project area traffic patterns are more or less similar to those of traditional traffic assignment, whilst inside the project area the effects of differences in information availability can be modelled.

Within the project area, 'local traffic' is assumed to have full knowledge of the road network in the project area and behaves accordingly, by always searching for the best routes available, even if that means using residential or rural roads. 'Non local traffic', on the other hand' is assumed to be not familiar with the road network in the project area. They therefore favour the use of through roads and will use residential or rural roads only if necessary (when there is no reasonable alternative). In order to achieve this behaviour, all roads inside the project area that are classified as residential or rural, are penalized by adding a fixed GTC. Tests have shown that adding approximately 50% of the original GTC value ensures that 'nonlocal traffic' behaves according to expectations. In practice, this means that 'nonlocal traffic' prefers to take a 2.5 kilometre detour over through roads in order to avoid 1 kilometre of residential/rural road.

The altered road network that is presented to 'nonlocal traffic' ensures that most road users will avoid the local detours and follow the main through roads instead. If however, these through roads are not the officially signed detours as prescribed by the road authorities, it is necessary to perform some additional measures. Then a reduction of GTC on all links of the signed detours for all non-local users will ensure a sufficient use of the signed detour.

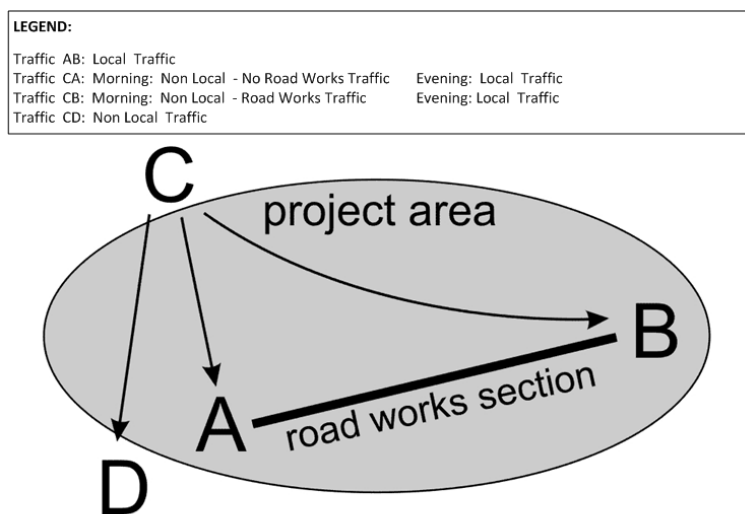


Fig. 3. Definitions of local and non-local, road works and no road-works traffic.



In Fig. 3 an example is provided to explain the definitions of ‘project area’, ‘local traffic’, ‘non-local – road works traffic’ and ‘non-local – no road works traffic’. Because A and B are both inside the project area they are thus considered as ‘local’, the traffic from A to B, which clearly has the opportunity to use the road works section, is classified as ‘local traffic’. C and D are both outside the project area and there is not a good reason why traffic between the two would use the road works section, the traffic from C to D is therefore classified as ‘nonlocal – no road works traffic’ even though they cross the project area. In the morning rush hour most people leave from home (where they are familiar) and drive to work (where they are not so familiar). In the morning rush hour, traffic from C to A is therefore classified as ‘nonlocal – no road works traffic’, for they live outside the project area. In the evening rush hour, however, people from C to A are familiar with the project area (they live at A and drive home from work) and are therefore classified as ‘local traffic’. The traffic from C to B might normally use a part of the road works section. In morning rush hour, traffic from C to B is therefore classified as ‘nonlocal – road works traffic’. In the evening rush hour, people drive back to home, are therefore familiar around B, and are therefore classified as ‘local traffic’.

So we state that the alternative traffic assignment provides each road user the network he deserves. Road users that are not familiar are penalized if they are using rural or residential roads and, if faced with road works, will tend to follow the directions of the road managers. The alternative traffic assignment model contains in fact a four-step approach itself:

1. Preliminary assignment of ‘local traffic’, to ensure that most ordinary roads in the project area are not used by ‘nonlocal traffic’;
2. Assignment of ‘nonlocal – no road works traffic’, taking into account the preliminary assignment of ‘local traffic’ and the added GTC values on rural and residential roads;
3. Assignment of ‘nonlocal – road works traffic’, taking into account the preliminary assignment of ‘local traffic’, the assignment of ‘nonlocal – no road works traffic’, the added GTC values on rural and residential roads and the subtracted GTC values for prescribed detours; and
4. Definitive assignment of ‘local traffic’, taking into accounts the assignments for ‘nonlocal – no road works traffic’ and ‘nonlocal – road works traffic’.

4. Example

We now want to demonstrate the working principles of the framework, and specifically how hindrance can be determined based on the outcomes of the alternative traffic assignment.

Demand

We use so-called OD-matrices from an existing transport model that was developed for this region. Would this have not been the case, such an OD-matrix would have had to be developed from scratch, using socio-economic data of all zones (i.e. number and type of inhabitants, number and type of workplaces, specific activities as schools, hospitals, etc.) and a so-called distribution function that denotes for each GTC the willingness to make a trip of a certain impedance, i.e. GTC. Obviously such a function is strictly decreasing. Using local and non-local centroids, local and non-local OD-flows can be defined, as was specified in the previous section. Demand is further defined for generally four time periods, i.e. morning peak, off-peak day, evening peak and off-peak night.

Network

All road segments in the direct neighbourhood of the area where maintenance works take place are defined as “local roads”, for which we assigned altered GTC values. Then, altered GTC values for the signed detours are added as was explained in the previous section. Centroids directly around the road works area were defined as “local centroids”. Obviously the blocked segments, i.e. the locations where the actual maintenance work takes place, are deleted from the network model.

For each road segment a travel time function is defined, where travel time is assumed to be a function of flow and the capacity of that road segment. This information is sufficient to run the alternative traffic assignment, which yields for all roads in the network a value for traffic flow. With this flow it is possible to determine externalities of traffic, e.g. noise levels, CO₂ emission, travel times and air quality.

For the regular situation without any maintenance works a traditional equilibrium assignment yields traffic flows for all roads in the network. If we now compare the new situation with maintenance with the current, equilibrium situation, hindrance as a result of the maintenance works can be determined.

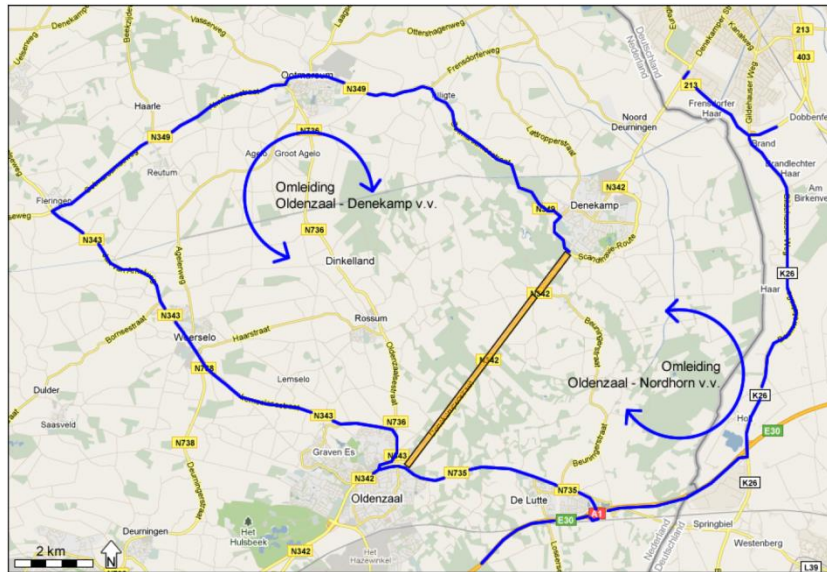


Fig. 4. Project area with rerouting options

Case N342

As a case we choose a maintenance project that was executed on the N342, a regional road in the eastern part of the Netherlands between the cities Oldenzaal and Denekamp. During a period of 4 weeks the N342 was completely blocked. Road authorities installed a number of rerouting options that were indicated using temporary road signs, as depicted in Fig. 4.. Before and during the period of blockage, traffic counts were executed to be able to monitor traffic flows in the network. Locations are depicted in figure 5. For this area a regional transport planning model is operational. Part of this planning model is a series of OD-matrices, for the different time periods. These OD-matrices are calibrated using traffic counts in the before-situation, i.e. the situation without road works.

During the blockage traffic counts took place to be able to monitor the changes in traffic flows in the network. It appeared that a new equilibrium situation occurs after approximately one week. So, it takes cardriver approximately one week to get adjusted to the new situation, and find an alternative route that they are comfortable with. If we now perform a regular equilibrium assignment for the altered road network, i.e. the situation with N342 blocked, we find that the traffic flows differ significantly when compared to the traffic counts. Then, we introduce the alternative traffic assignment method, and we calibrate the adjustments of GTC as was indicated earlier by penalizing rural roads and decreasing GTC for signed alternative detour routes. So for this situation our framework could have been applied to determine altered traffic flows as a result of complete blockage of N342. However, also for other blockage-regimes, and other detour-strategies the alternative assignment method will yield altered flows and as a result hindrance can then be determined. So more general using the framework for the whole area for any long term maintenance strategy the amount of hindrance and total amount of delays can be determined.

5. Conclusion

Traditionally road maintenance strategies are developed using some form of life cycle cost analysis and/or life cycle analysis. The cost function generally contains cost that are directly linked to the actual construction of the road. We have argued that in an increased utilised environment, where road infrastructure spare capacity generally decreases, hindrance in terms of delays and externalities as noise, safety and air quality, become more and more important assessment criteria. Since hindrance is generally not restricted to the area where the maintenance work takes place, we have further argued that delays and externalities should be determined on a network level, rather than on a local level. Externalities and delays are determined as a result of a different level of service on the network and altered flows.

For this we have developed a decision framework where, given a set of decisions regarding the execution and construction type and some additional traffic management measures, delays and hindrance on a network level



can be determined. It appeared that traditional route choice models are not applicable in a situation where roads are fully or partially blocked as a result construction work. For this we have designed an alternative assignment method where local and non-local drivers and network elements are distinguished, and signed detour routes can be input for such a model. The alternative assignment model was calibrated for a real life situation and in an example it is demonstrated how the framework should be applied. As result, using the framework, any strategy on road maintenance can be assessed for multiple objectives, i.e. cost, delay and hindrance. Applying a pareto analysis may then support the decision of selecting the best maintenance strategy.

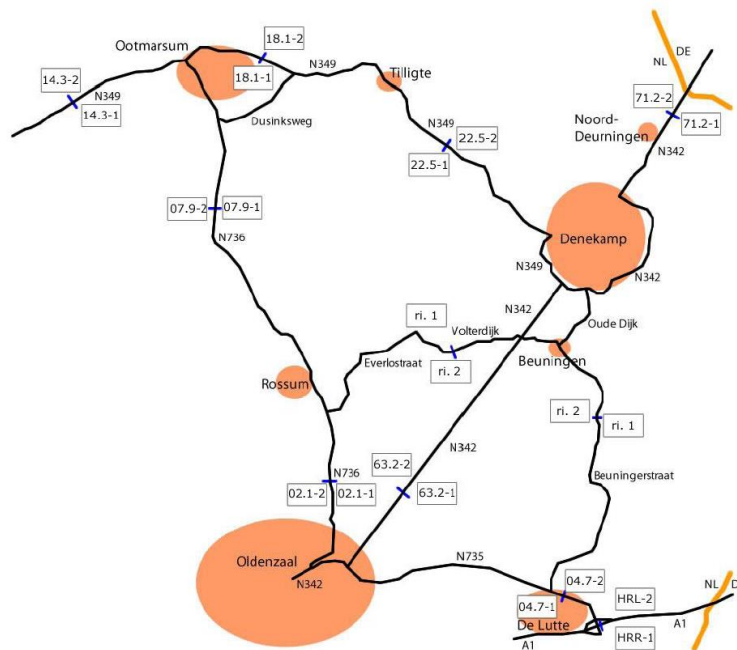


Fig. 5. Location of the traffic counts

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