Modeling Traffic Hindrance Caused by Road Maintenance

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ABSTRACT: The past decades have shown an exponential increase in the use of the road network. The increased loading requires more frequent maintenance work, whereas the demand for undisturbed traffic flows restricts the opportunity for doing roadwork. However, road maintenance is required to keep roads in acceptable condition. As a result, maintenance activities do have more frequent and more severe impacts on society. These impacts involve both traffic obstructions and traffic externalities, together defined as traffic hindrance. Road agencies are currently facing the problems of coping with traffic hindrance on a network level. Effectively estimating traffic hindrance is essential to accurately schedule and perform maintenance with reduced traffic hindrance. To assist road agencies in deciding on maintenance methods, traffic management and scheduling, we develop an infrastructure management system that will provide the trade-off between total costs and traffic hindrance. For this aim we work on a theoretical framework that is able to define the relationships between road maintenance characteristics, traffic effects, maintenance costs and traffic hindrance for road works. The paper describes a literature survey after models and systems that combine road maintenance works with traffic management. Additionally, the paper focuses on the development of a theoretical framework that is based on a combination of state-of-the-art research in the fields of road construction, traffic modeling and impacts on society. The paper further describes the development of alternative traffic assignment definitions in relation to traditional traffic assignment. We think that the alternative traffic assignment forecasts traffic behavior more accurately, at least in order to study regions in which road works are to be scheduled.

1 INTRODUCTION

The use of the Dutch infrastructural network has substantially increased during the last decades. As a result road maintenance work is done more frequently, this means that the availability of sufficient road capacity is also under stress.

In the Netherlands, as in other densely populated areas, much attention is given to the externalities of traffic, such as noise, air quality and traffic safety. This also holds in case of road maintenance works, where there is a specific focus on hindrance and nuisance. Here hindrance is defined as the objectively measurable externalities induced by road works, and nuisance is defined as the way in which hindrance is perceived.

Different factors may influence this, such as the way in which the work is executed but also the way in which traffic management measures are implemented to guide the remaining flows as good as possible.

Nowadays, limitation of traffic hindrance and nuisance is often part of the tender procedures. The so-called EMAT (Economically Most Advantageous Tender), principle (Dreschler 2000) is
implemented by the national Dutch authorities in order to create fair competition between contractors. This implies that the quality of the work in combination with the price determines the success of the bid.

The quality of a road construction project is not only determined by the improvement of the road pavement, but also by the way in which the work is executed, since specifically this determines the amount of nuisance. The focus in the research project “Road management with limited hindrance and nuisance” is to find a balance between acceptable costs of road building projects, quality improvement that those projects will realize and the amount of traffic hindrance and nuisance that those projects will cause. This paper discusses a theoretical framework (fig 2). This framework is able to determine for each road maintenance strategy for a certain region, costs and impact on traffic flows and, as a result, the effects on externalities. This framework can then be used to determine an optimal planning of road maintenance works for a specific region for a longer period of time.

2 THEORETICAL FRAMEWORK

2.1 Road maintenance

The transport network is a public private commodity; it is of high value for society and it represents a huge capital investment. To be able to keep the value of this commodity at a high level it is important to properly maintain it, in order to avoid capital loss by poor functionality of the system. If the quality of the road network can be kept above a predefined threshold level, safe traffic and transport will be possible and accessibility will be ample. This can only be achieved by adequate and timely scheduled road maintenance activities. As a result maintenance is included in the theoretical framework, as shown in Figure 2.

2.1.1 Road management and maintenance

The starting point within the proposed theoretical framework is the quality of the pavement. Most administrations base their strategy for road maintenance on the present state of the pavement (also known as condition based maintenance) and the importance of the pavement within the road network (Burningham & Stankevitch 2005). Especially the network structure and its robustness are important features when determining a maintenance strategy. The network robustness provides a way of prioritization (see for instance Scott et al. 2006), in which critical links require more effort in mitigating traffic hindrance. Based on such a maintenance scheme we can then look at several strategic or policy options to restrict traffic obstacles. The “Planning” consists of a series of road works, including the time of execution and the pavement materials (e.g. concrete or asphalt). These are decision variables in relation to the road maintenance works. Following this planning a maintenance strategy can be derived, where for each location the frequency of maintenance is included.

Maintaining infrastructure pavements can be done cyclic or condition dependent (choosing one or the other as part of the maintenance strategy). Cyclic maintenance is maintenance planned in a fixed frequency. Between two periods of maintenance there is no road works (except emergencies) and thus no hindrance. Cyclic maintenance makes it possible to plan different road works within a network in such a way that the hindrance is acceptable. BB&C studied in 2008 three cases of maintenance at motorways (BB&C 2008). Among others, the study focused on the differences between cyclic and condition based maintenance. The conclusion was that there is no big difference in costs if a pavement cyclic maintained compared to condition based maintained. However, in this study subjective hindrance was not taken into account. Cuelho et al. (2006) concluded in their study that in the US almost no pavements are maintained “cyclic”. This means all the road works are planned condition based.

2.1.2 Doing Road Works: The construction phase.

Based on the maintenance strategy, road work projects are planned for a specific time and place. During the construction phase there are possibilities to reduce traffic hindrance. This can be done by choosing the most appropriate way of constructing given the condition of the road and considering the desired level of throughput of the road link (Brown 2007). Taking this into account, the way the project is executed can be seen as a decision variable. By choosing a spe-
pecific 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 (management) of phases and choosing construction methods and/or procedures and work hours, day or night. In practice the construction method is often adjusted precisely on mobility management and vice versa.

The main aspects of maintenance operations are: location, time, costs and effectiveness. Each measure has impact on throughput itself, but a safety margin is needed as well as enough construction time and sufficient budget (CROW 2005). The result of such a measure is improvement of the actual quality and the life span of the pavement (Brown 2007).

Using the framework, we calculate the changes in capacity of the road link based on construction site and construction duration. During construction a part of the road is closed both for construction and safety reasons. Roadblocks and hindrance are in this case unavoidable. This statement proves that both variables “workspace”, “mobility management” and “regulations regarding safety” are strongly interdependent (CROW 2003).

To be able to simulate traffic flows and traffic hindrance based on possible construction methods, as well as calculating costs and effectiveness, we develop a theoretical framework (Huerne 2012). The framework is a tool or a model that may help in deciding what the best construction measure should be (costs and effectiveness) in relation to acceptable traffic hindrance. It determines what the effects of a specific road maintenance works are, and supports the trade-off between the different effects. Figure 1 shows an example, where for different solutions of a road maintenance work the effects on two criteria, cost and hindrance, are shown.

![Costs versus Hindrance both in €](image)

Figure 1: Different solutions of a road maintenance works and the effects on two criteria, i.e. costs and hindrance, both expressed in €.

2.2 **Traffic effects during road works**

2.2.1 **Part i: “Infrastructure capacity during Road Maintenance”**

In order to maintain and/or improve our pavements, workspace and extra safety margins are needed during construction. That in itself reduces the traffic capacity of the road network. Capacity reduction takes place just along or on the road link under construction. A complete road block will obviously reduce the capacity to zero, whereas roadwork on the shoulder reduces the road capacity only partly (Rijkswaterstaat 2002). The use of traffic measures and traffic management affects the capacity of the network both at the location of the road works as well as at other places within the network. For motorways this has been studied extensively (Benekohal 2003). On secondary roads, however, much less is known about capacity reduction as a result...
of road works. Discussion with road authorities indicates that for safety reasons road maintenance on secondary roads often requires a complete road block.

In our framework we estimate hindrance as an effect of an altered road network in terms of capacity reductions and traffic management measures. This is then modeled using a traditional four-step model, using the altered road network as input (Ortuzar 2001).

![Figure 2: The theoretical framework.](image)

### 2.2.2 Part ii: “The four step model”;

The four-step model consists of: trip generation, trip distribution, Mode choice and route assignment. The infrastructure road network is important input for the four-step model. 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 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.

All these choices result in a traffic-flow load level on the network. This means that for each link in the network it is known by which travellers it is being used (in terms of origin and destination), by how many it is used (flow or intensity) and which speed prevails. In general it is assumed that the more cars use a link, the lower the speed becomes. Under regular circumstances (no road works/blocks) it is assumed that the transport system is at equilibrium which means that no traveler does have advantage by unilaterally changing his or her route. Once road construction is taking place this situation may no longer be valid. It will very much depend on the
impact on capacities in the network (Brög & Schädler 1999) and on additional traffic measures how travellers will respond, and how, as a result, the situation on the network will change.

**Route choice during road maintenance works**

A traditional four step model is very well capable of dealing with the situation where capacities are altered at several locations in the network. However, when additional traffic management measures are implemented, such as information strategies or signposted alternative routes, specifically the fourth step, where routes are chosen, may cause some severe problems.

### 2.2.3 Part iii: “Road works externalities”

In our framework externalities of traffic determine hindrance and nuisance. Examples are air quality, noise, safety and the emission of greenhouse gases. In all cases externalities are determined by traditional traffic flow qualities as speed and flow. In return, these qualities are output of the four step modeling approach. Now, when the base situation in terms of speed and flow, is compared to the situation where maintenance work takes place, and where maybe additional traffic management measures are implemented, externalities can be compared. In addition, for both situations route choices are compared and changes in travel times can be determined at an individual level.

In earlier paragraphs all external effects were called “hindrance”. From here we will make a difference between nuisance and hindrance. These two together we call externalities. Main reason for this lies in part iii of the theoretical framework (Figure 2). Here a distinction is made between the objective part of externalities (measurable variables like minutes delay, miles of detour etc) and the more subjective part called nuisance (smell, annoyance, decrease in safety etc). Both types of externalities require their own approach (Stallen 1999).

Traffic nuisance results in complaints and dissatisfaction. Complaints are directed to the main road authority, the contractor (if applicable) or the media (Wismans et al. 2011). Currently there is not a reliable indicator to quantify traffic nuisance. Often we use information provision (to the traveller) as a decision variable (Rijkswaterstaat 2007). Public information management, for instance, has been shown to improve the involvement of companies near work zones (Tuddenham 2008). However, the experience of traffic nuisance depends, apart from others, on information provision about the hindrance (accurate and timely), credibility of the administration and/or road contractor, duration of the road block, time and location of the disturbances. Experiencing hindrance also depends on personal characteristics of the concerned individuals On the one hand more and more use is made of traffic hindrance to classify the effects of road works, whereas on the other hand heavily is being invested in affecting the experience of nuisance by way of information services and communication with travellers and/or residents. In practice both types of externalities (objective and subjective) have not been coupled yet.

### 3 TRAFFIC PATTERN MODELLING.

It was demonstrated (Hermelink 2011) that route choice in a traditional traffic assignment approach is not always able to predict the traffic patterns during road works correctly. Generally speaking, we conclude that the traffic flows over local detours and local routes are overestimated, whilst the traffic flows on official (signed) detours are underestimated. To overcome these problems an alternative traffic assignment approach was developed.

#### 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 actual payments (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 behavior is not so pliable, road users are not constantly checking the alternative routes, in the long term people will distribute over the various alternative routes. After all, when road users are queuing at the same in-
tersection 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’ behavior 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. 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 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.

During road maintenance, however, road users do not have the time to gather knowledge and move into equilibrium. They are suddenly confronted with a closed (or partially closed) road and 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

The 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, whereas road users that are unfamiliar are likely to avoid residential and rural roads. Therefore a project area that comprises of the road works sections, the signed detours, and the surrounding area is defined. 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 the 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 modeled.

Within the project area, ‘local traffic’ is familiar with all the roads and has a good understanding of the situation on these roads. That is, ‘local traffic’ is assumed to have full knowledge of the road network 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 not familiar with the road network in the project area. They therefore favor 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 behavior all roads inside the project area that are classified as residential or rural roads are penalized in terms of generalized traffic costs. In most traffic simulation packages this can easily be achieved by adding a fixed GTC to these road sections. 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 mile detour over through roads in order to avoid 1 mile 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. There are, however, a number of situations in which these through roads are not the detours prescribed by the road managers. It is, for instance, not unlikely that such a detour forces a significant amount of ‘nonlocal’ traffic through a city centre even if there is a ring road available. More specifically, there is still no incentive for the ‘nonlocal’ road users to follow the prescribed, signed detour.

The signed detour is not attractive alternative, if an alternative at all, for all ‘nonlocal traffic’. In fact, most ‘nonlocal traffic’ does not even enter the project area. If, for instance, the project area is around the N50 mentioned earlier, all traffic from Amsterdam to Rotterdam
(both in the West of the Netherlands) is considered ‘nonlocal traffic’, but none of them will ever use the N50. In fact, the signed detour is only attractive to those ‘nonlocal’ road users that might encounter the road works. The ‘nonlocal’ road users are therefore subdivided into two categories: ‘nonlocal – road works traffic’ that might use the road works section and ‘nonlocal – no road works traffic’ that will never use the road works section. The latter group is, usually, the majority and behaves exactly as the ‘nonlocal traffic’ described earlier.

The ‘nonlocal – road works traffic’ is also affected by the increased GTC on rural and residential roads, as is all ‘nonlocal traffic’. This type of traffic, however, is inclined to use the prescribed and signed detours. They are unfamiliar with the environment and, facing road works, have little alternative than to follow the detour designed by the road managers. This behavior is modeled in much the same way as the penalty that is imposed on rural and residential roads. In this case, however, the GTC of the prescribed and signed detours is reduced, making it a more favorable alternative. Preliminary studies show that subtracting approximately 50 – 80% of the original GTC value ensures that most ‘nonlocal – road works’ road users follow the prescribed detours. In practice this indicates that they are willing to take a 2 – 5 mile signed detour even if there are alternative routes that are only 1 mile long.

Figure 3 illustrates an example to explain the definitions of ‘project area’, ‘local traffic’, ‘nonlocal – road works traffic’ and ‘nonlocal – no road works traffic’. Because A and B are both inside the project area are thus considered ‘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’.

In conclusion 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 resi-

![Figure 3: Alternatively traffic assignment during road works and its definitions of local and non-local, road-works and no road-works traffic.](image-url)
dential roads and, if faced with road works, will tend to follow the directions of the road man-
agers. 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 pro-
ject 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 as-
signment 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 account the assignments for ‘non-
local – no road works traffic’ and ‘nonlocal – road works traffic’.

3.3 Application of the developed framework

The developed theoretical framework does have six decision variables. Together, road admin-
istrations and contractors, are challenged to tune the measures related to the road works and
traffic management in such a way that concerning the output variables an optimum exists. Such
an optimum would preferably include; a. a rise of road construction service level, b. acceptable
costs, and c. acceptable level of externalities.

The proposed theoretical framework assists the exploration of the possible effects of choices
during planning of road works in combination with possible traffic measures.

4 EXAMPLE CASUS N342

We now want to explain the working principles of the alternative traffic assignment based on
the casus N342. The N342 is the main road between Oldenzaal en Denekamp, a larger regional
road in the eastern part of the Netherlands close to the border with Germany. For performing
large reconstruction works at the N342, the road became completely blocked over a couple of
weeks by the regional road authority. Detour routes pushed the traffic over regional roads
and partly over motorways. The traffic model “Regio Twente” forecasted the effects of the road-
block, but strongly underestimated the effects of rat-run traffic and overestimated traffic that
make use of the official detour routes. We know this from extra traffic counts we did during the
road works. It was concluded that the traditional traffic assignment did not work properly.

The proposed changes in traffic assignment, as discussed in chapter 3, are implemented
in the last step of the 4-step model. The road links directly in the neighborhood of the road works
section (roughly the Oldenzaal, de Lutte, Denekamp - Ootmarsum area) were now defined as
“local roads”. We gave for that reason changed GTC values to the 30 and 60 km/h roads inside
the model. Further, centroids directly around the road works area were defied as “local cen-
troids”. This implicates that local centroids do not feel the disadvantage of increased GTC val-
ues on local roads.

The overall result was that rat-run routes on regional roads were used less frequently when
compared to the traditional traffic assignment. This results in a shift of traffic to the official de-
tour routes. All together the alternative traffic assignment model produces results that are much
more in line with actual measurements of traffic flows. Figure 4 shows how traffic flows will
change if the main route Oldenzaal – Denekamp becomes blocked. The results are calculated
using the advanced traffic assignment implemented in the Regional Traffic model. Green means
increase in traffic flow due to the road block whereas red means decreased traffic flow due to
the road block. The results are calculated using the alternative traffic assignment definitions
implemented in the Regional Traffic model.
5 USE OF THE FRAMEWORK AND ADVANCED MODELLING

Who is going to use the developed theoretical framework including the advanced modeling? We aim to work out the developed tools into a user friendly program, which might be seen as a Decision Support System (DSS). The system might be used by Road Authorities or agents that manage road infrastructure system including traffic flows contact to the environment, communication with the user of infrastructure and service providers, and are responsible for maintenance of the pavements and road pavement quality (RAMS specifications: reliability, availability, maintainability & safety). These could be national or regional authorities or commercial agents. However, we think that our model or program can be used for those who must decide about what maintenance road works activities must be done and when (also in relation to each other concerning a road network with different needs and characteristic traffic patterns). The program/framework can help infrastructure network management in taking the right decision, it makes the effects of choices visible in terms of virtual costs related to hindrance in relation to actual costs for maintenance for different measures (see figure 1). The program/framework can also be used for studying different road owners’ strategies. It does not make choices, but makes the effects of choices visible. The decision must be made by the responsible road infrastructure operator.

6 SUMMARY

The paper briefly discusses the theoretical framework and provides extensions on the well known 4 step model by Ortuzar & Willumsen (2001). The theoretical framework is the blue print for the developed decision support system. However, in case of road works where also traffic management measures are implemented, a traditional traffic assignment model lacks realism. Therefore a new assignment model was implemented and tested. The results of a number of preliminary tests were reported (Figure 4), and the alternative assignment approach clearly outperform the traditional approach in terms of usage of officially signposted detour routes.
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