MICROSIMULATION OF WORK ZONE DELAYS AND APPLICATIONS IN PAVEMENT MANAGEMENT

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ABSTRACT

Operation and maintenance activities on roads will to a varying extent affect the traffic flow. Reduced speed limits past the work zones will cause some delays but the main impacts will occur when the road´s capacity is reduced in case of lane closures. This increases the probability of queues which may contribute to significant delays for the road users. Delays result in costs for the society. Additionally, queues increase fuel consumption, pollutants, risk for accidents as well as wearing of vehicles and roads.

This paper examines the use of microsimulation as a method to estimate the road user delays and discusses implementation issues and applications. The work zone delays have been implemented in a life-cycle cost analysis (LCCA) model. An LCCA was performed for the selection of wearing course type.

The key finding of this study is that the high level of detail gives the opportunity to model different work zone types, road types and speed limits using one method. In comparison to other methods, most which are specifically developed for work zone analysis, microsimulation has previously been used in numerous traffic capacity studies. This gives a certain confidence, in conjunction with performed calibrations and validations, that the results are valid. The performed LCCA indicated that the road user delay costs contribute to a significant share of the total life-cycle cost. The delay costs did therefore affect the selection of wearing course with respect to the estimated life-cycle costs.

1 INTRODUCTION

In many countries the 50's to the 70's was a period of extensive expansion of the European road network. Many of the roads constructed in this period have now been in service for more than 40 years and are approaching the end of their service life. This will require considerable resources of the road administrators to manage the necessary rehabilitation projects. However, this will not only strain the road agencies' budgets but also impact the road users and the society as a whole.

There are therefore growing concerns of increased road user costs when more extensive maintenance activities will be required to restore and extend the roads' structural and functional capacity. To be able to perform the necessary activities, deployment of work zones will be needed. The work zone must be accompanied by speed limit reductions for safety reasons of the road workers and road users. Speed limit reductions pass the work zone will result in delays for the road users. The most significant impacts will, however, emerge because of the work zones reduce the capacity of the road, especially if lanes are closed. In higher traffic flows, this will result in the forming of queues upstream of the work zone. The road users will consequently experience delays in queues or detours (NJDOT, 2001). In addition to delays, road users may be affected be increased fuel consumption, risk for accidents and wearing of vehicles. From an economic perspective this will firstly cause increased costs for the road users (Lewis, 1999). Delays for private persons may result in lost work time or spare time, while commercial vehicles may miss important deliveries with consequences in downstream logistic chains. Depending on their respective valuation of time and delays, a delay will be associated with a certain cost. Increased fuel consumption causes fuel costs and increased vehicle wearing affects the depreciation. From a societal point of view, these costs are also associated with socio-economic costs. For instance, increased fuel consumption results in pollutions on local, regional and global level with various environmental impacts.

In recent times the long durations of road works in Stockholm have been discussed in the Swedish media. Road users have expressed annoyance of the amount of work zones in the city while the roadworks often have appeared to only be performed during the day shifts. The Swedish Transportation Administration (STA) and the municipality of Stockholm have defended themselves that they have budget constraints to obey and are therefore not able to pay for the extra costs associated by having the contractors to work during night time. In addition, the work during nights and weekends is also associated with problems of scheduling and the availability of workers (Tang & Chien, 2008). For cost-effective management of work zones, it therefore becomes important to have reliable tools to assess the work zone impacts. However, the impacts are also important to consider during the planning and design phases of roads in order to be able to minimize the life-cycle costs.

Life-cycle Cost Analysis (LCCA) is an economic evaluation method used to find the optimal investment alternative that is estimated to minimize the life-cycle costs. By discounting future costs to a net present value, usually to the time of investment decision, can cost flows occurring at different times become comparable. By including all future maintenance efforts for the road operator, it gives the opportunity to assess an investment's impact on future maintenance budgets. However, when performing a LCCA in order the find the optimal investment alternative it also becomes important to assess the impacts on the road users (Ozbay, Jawad et al., 2004). In FHWA (1998) an analytical approach was presented to estimate the road user costs when performing a LCCA. In order estimate the work zone delays are several input parameters required. This includes, for example, work zone capacities, queue discharge rates and queue speeds. These parameters have to be estimated for each work zone design from, for example, traffic measurements. Microsimulation is a traffic simulation method that offers the highest level of detail in the representation of traffic flows. If the microsimulation software is being able to simulate the work zone behaviour sufficiently, the method has the advantage that the above-mentioned parameters are results of the simulations rather than input parameters. This raises the question whether microsimulation may be a suitable method to estimate work zone delays and especially for applications in pavement management.

1.1 Aim and purpose

This study has the purpose of examining the use of microsimulation as a method for work zone traffic analysis and to develop a methodology to estimate the road user delays. The results should be able to be implemented in tools for various work zone management applications. The purpose therefore also includes examining the use of work zone delay costs in pavement management.

The aims of this paper include:

- Present a methodology to estimate work zone delay costs using microsimulation
- Discuss the suitability of microsimulation for work zone analysis, implementation issues and possible improvements
- Application of work zone delay considerations in pavement management

2 BACKGROUND

In NJDOT (2001) the road user costs have been associated with two level-of-services: free-flow conditions and interrupted-flow conditions. In the following sections is the delay characteristics of the two level-of-services discussed.

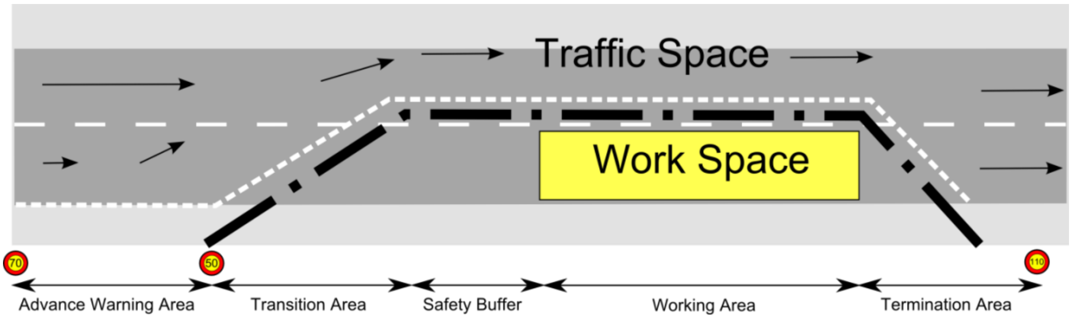

Figure 1: Configuration of a typical work zone on a motorway.

2.1 Work zone delays in free flow conditions

In free-flow conditions, the vehicles can drive at their desired speed and are not constrained by conflicting traffic streams (TRB, 2000). This level-of-services is associated with low traffic flows which results in low densities. Subsequently, on motorways therefore are usually no problems for vehicles to merge to the work zone’s open lane.

The delays in this flow condition are therefore mainly induced by the speed limits in the work zone area and advance warning area. For example, in Sweden, the regulations of the speed limits are dependent on work intensity and the work zone’s protection capabilities (SRA, 2009). If unprotected workers are closer than 2.5 m to the traffic space, then the actual speed must be lower than 30 km/h. In normal work conditions the actual speed should be lower than 50 km/h. For stationary work zones with approved concrete barriers, a maximum speed of 70 km/h is allowed. In addition, speed limit reductions are required in the advance warning area with purpose of preparing the vehicles to reduce the speed to the posted work zone speed limit. In NJDOT (2001) are the delays, in this condition, associated with two components. The first component is speed change delay being associated with the required decelerations and accelerations in the advance warning area respectively in the termination area (Jiang, 1999). The second component is the work zone delays, which are dependent on the actual speed in traffic space area and the work zone's length. NJDOT (2001) states that studies have showed the delay costs to contribute to over 90 percent of the road user costs in this level-of-service.

2.2 Work zone delays in saturated flow conditions

In saturated flow conditions, the traffic flow is close to, or has exceeded (oversaturated flow), the work zone capacity. This level-of-service is characterized by emerging conflicts between different traffic streams. When the work zone is not able to service all incoming traffic, there is an increase in density upstream of the work zone. In turn, this decreases the headways between the vehicles which lead to more problematic merging on motorways. While the traffic flow is increasing closer to the capacity, this will eventually result in the formation of queues on the link upstream of the work zone.

When queues are formed, it usually results in significant delays for the users. In NJDOT (2001) it is stated that in this condition, studies have showed that 90 percent of the road user costs is related to delay costs and queue idling vehicle operating costs. The delays may therefore be one the most important cost components that need to be assessed.

3 METHODOLGY

3.1 The choice of microsimulation for work zone assessment

The choice of microsimulation as work zone analysis method was based on a need to develop an application that can calculate delay costs for several types of work zones and road types. In analysis methods less detailed compared to microsimulation, the work zone capacities are usually required as an input, which has to be based on for example traffic measurements or traffic simulations. Traffic measurements are usually time consuming and expensive. Since the application was supposed to be used for several road types and work zone configurations, microsimulation was considered to be suitable for this purpose. Microsimulation's high level of detail makes it capable to capture different work zone configurations, lane closures and traffic control types. It should, however, be noted that the choice of Aimsun as microsimulation software was based mainly on availability.

Early in the study it was concluded that it is necessary to run a large number of simulations to be able to cover all possible combinations of influencing factors. With respect to this, the first step in the study was to identify the most important factors with respect to delays. In the Highway Capacity Manual (HCM, 2000) is an equation presented in order to estimate a rough figure of a work zone's capacity. The primary factors considered in the equation are the base capacity, work zone configuration and heavy vehicle adjustment factor. Additionally, the manual also present adjustment factors to consider work zone activity, lane widths and adjacent on- and off-ramps. The factors included in HCM (2000) and simulation experiments formed as a basis when selecting the most important factors to consider. In conclusion, it was decided to include different road types, work zone configurations, average annual daily traffic (AADT) volumes and heavy vehicle ratios.

The road and work zone types selected to be included in the study was the following:

- Four-lane motorway
  - Inner-lane closure
  - Passing-lane closure
  - Mobile work zone
  - Only speed reduction
- Six-lane motorway
  - One-lane closure
  - Two-lane closure
- 2-lane road
  - Traffic signal control
  - Flagger control
- 2+1 roads (alternating 1 and 2 lanes)

The basic concept of the implementation was to first model base models for normal conditions for each road type, model different work zone configurations and thereafter run the simulations. By running the simulations with different traffic flows and heavy vehicle ratios, it was possible to estimate the delays by computing the difference between the travel time during normal conditions and when a work zone is present. The simulation results could be used to develop relationships of the delays with respect to different road types, work zone types, traffic flows and heavy vehicle ratios. The relationships could thereafter be used as a foundation for applications in which the delay costs can be calculated in a simplified manner.

3.2 Assumptions and limitations

Since the speed limit reductions in the advance warning areas were considered to have less impact on the resulting delays, all models were generalized to one type of speed reduction. The traffic space area was not included in the motorway models since the length of work zone was supposed to be variable. As a simplification, the delays related to work zone passing were instead calculated ex-post by using the actual speed and distance. In the initial phase of the study was only one hourly distribution used for the daily traffic. This was an hour distribution commonly used in Sweden, which can be considered to represent an average traffic situation.

3.3 Calibration and validation of the base models

In microsimulation studies are calibration and validation of high importance to be able to produce trustworthy results. The study did therefore begin with calibrations of models for normal conditions. The calibrations were based on the speed/flow-relationships that have been developed by the Swedish Road Administration (SRA) as presented in the publication "Nybyggnad och förbättring - Effektkatalog" (SRA, 2001). These relationships are based on traffic measurements and are available for several road types, speed limits, traffic environments and road widths. The calibration process consisted of several iterations, in which the parameters of Aimsun's behavioural models were adjusted. From the simulations were the speeds and flows collected to be able to produce speed/flow-relationships with the aim of calibrating them to fit the speed/flow-relationships in SRA (2001). A validation was thereafter performed for a four-lane motorway using traffic measurements from the E4 motorway. The measurements only covered low flow levels. However, using regression analysis this could be extrapolated to medium flow levels (2000 veh/h/dir). Up to these levels it was possible to show that there were no statistical differences between the simulations and measurements at a 95 % confidence level using prediction intervals.

3.4 Work zone modelling and simulations

The calibrated models formed a basis for modelling of the work zone types. For the motorway models with four and six lanes were different lane close configurations modelled. For two-lane roads are flaggers a common way to control the access to the open lane between the driving directions. A simulation model for a flagger was developed in Aimsun using AIMSUN's application programming interface (API). The API makes it possible to change the behaviour of the microsimulation models during the simulations. This was used to program a module to simulate the behaviour of a flagger. The flagger model was based on the perception of how a flagger interacts depending on the incoming traffic, the traffic flow and work zone length.

During the modelling were verifications of the models performed. This by observing the animations to examine if the models captured the correct traffic behaviour in, for example, saturated flow conditions in presence of a work zone.

In the initial study it was identified that traffic flow and heavy vehicle ratio were the parameters that most significantly influenced the delays. It was therefore necessary to run simulations for each of the work zone models with varying traffic flows and heavy vehicles ratios. Since the traffic flows also varies depending on the time of the day, these fluctuations also have to be captured in the simulations. It was also necessary to consider when work zones only are deployed for shorter durations at different times of the day. Simulations were therefore also run for the different time periods for which the traffic flows varied. Considering these parameters and their combinations, it was necessary to run a large number of simulations. This was solved by developing an automatic process for running the simulations. All the results were saved in a shared database which later could be used to produce the relationships for the delays.

In stochastic microsimulation studies, it is important to take into account the deviations in the results. This can be solved by estimating the number of required replications for each simulation, based on the statistical significance level the results should rely on. This estimated value is dependent on, for example, the calibrations and the traffic flow levels. As mentioned above, it was necessary to run a large number of simulations in the study. In this study it was a trade-off between simulation time and deviations in the results. The estimated number of replications estimated was based on an average AADT using the methodology presented in Burghout, W. (2004). This resulted in an estimated number of 14 replications, which was rounded up to 15 replications.

The delays of each work zone type were calculated based on the simulation data. For each simulated traffic flow (AADT) and heavy vehicle ratio, it was possible to compute the delays based on differences in travel times in normal conditions and work zone conditions.

4 RESULTS

In this section the simulation results from two of the work zone configurations are presented. The rest of the results can be found in (Wennström, 2010). The section ends with a comparison to capacities and delays estimated in previous work zone studies.

4.1 Simulation results

In Figure 2 is the work zone delay costs presented for a work zone's configuration on a four-lane motorway. The work zone is setup in the inner-lane, in one of the directions and with a work zone length is of one kilometer. The speed limit is in normal conditions 110 km/h and the work zone's speed limit is 50 km/h. In lower traffic flows the delays are mainly affected by the delays introduced by the reduced speed limit. Around 20 000-25 000 veh/day, corresponding to around 1400 veh/h/dir during rush hour, can increases in the delays be discerned. As the traffic flow approaches the work zone's capacity, the delays increase with a higher rate. In over-saturated conditions, the delays are increasing in an exponential rate.

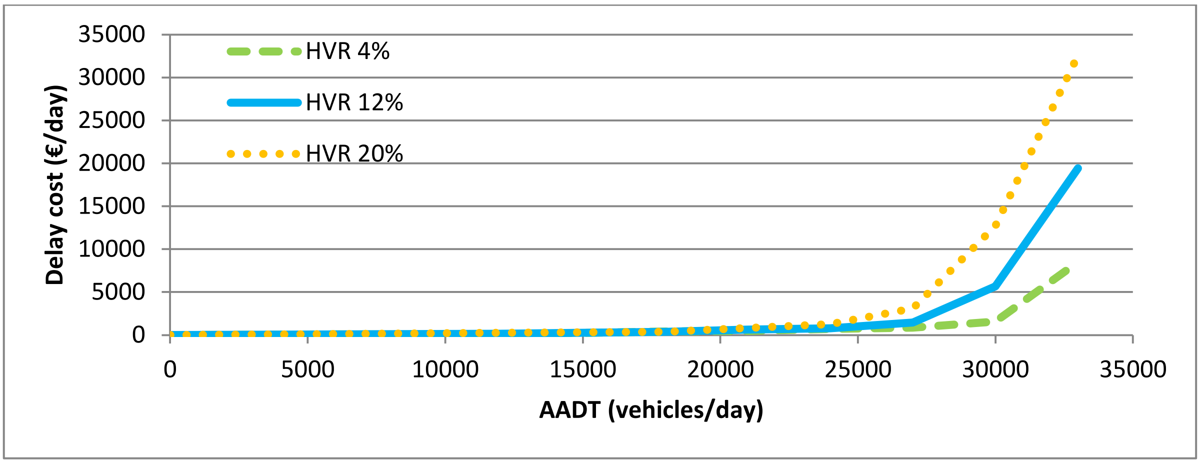

Figure 2: Delays costs for a 4-lane motorway lane closure (one direction) for varying Annual Average Daily Traffic (AADT) and heavy vehicle ratios.

In Figure 3 has the work zone delay costs been plotted for a two-lane road with a flagger as traffic control. In lower traffic flows are the delays increasing almost linearly, similar to the work zone on a motorway. In this level-of-service are there generally no problems for the flagger to discharge the short queues that forms during the waiting for the opposite direction to pass. The delays in this level-of-service are therefore, with high probability, only affected by the delay associated with the passing of the work zone. As it can be noticed in the figure, in medium-high traffic flows, the delays start to increase. Between the turns are queues formed upstream of the flagger's position, resulting in longer delays for the road users. When the traffic flows are higher than 6000 vehicles/day, there are considerable delay costs for the road users. The flagger is not able discharge the incoming vehicles between each turn for the directions, thus are the queues increasing rapidly.

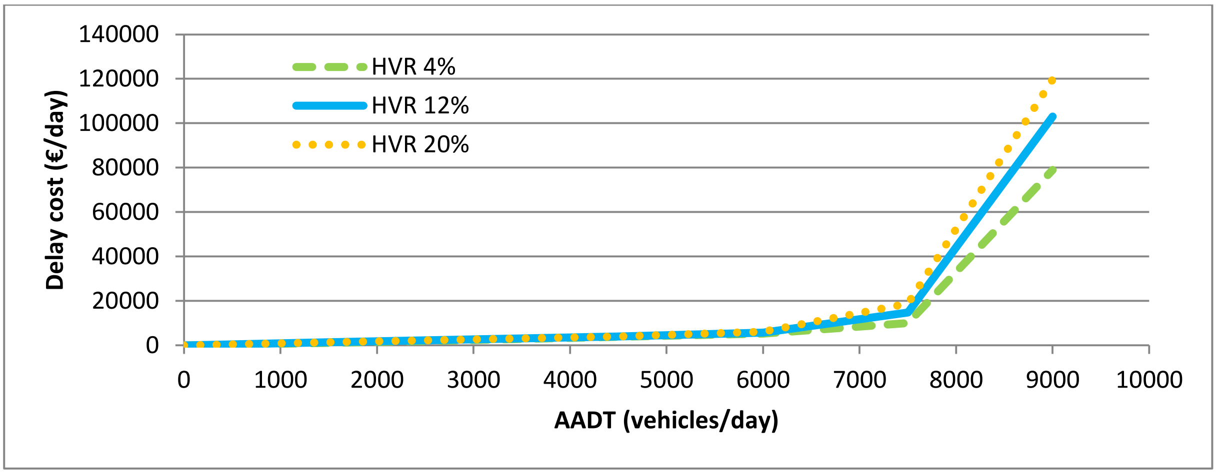

Figure 3: Delays costs for a 1500 m work zone on a two-lane road with a flagger operated traffic control

The road network in Sweden has a large, and increasing, share of “collision-free roads”. These roads consist of barriers, most of often wire, between the two driving directions. One direction at a time has an extra passing lane, often referred to as 2+1 roads. This study also included experiments to estimate work zone delays for this type of road, by introducing lane closures in either of the two lane sections or cross-overs in the case of one lane sections. The simulation results indicated large deviations of the queue delays. It was therefore not possible to obtain statistically significant delays originating from queues for this road type. One explanation for this behaviour could be that this road type has frequent transitions from two-lane sections to one-lane sections, thus having similar traffic behaviour as work zone lane closures. This also results in that the road type has a lower normal capacity than a corresponding two-lane road (Tapani & Robertson, 2009).

4.2 Comparison to other work zone traffic studies

Even if capacities reported in previous studies (Jiang 1999; Borchardt, Pesti et al. 2009) have showed large deviations, the estimated capacities from the simulations were in the similar ranges. In HCM (2000) is 1550 vehicles/hour used as a guideline for a work zone capacity with the same conditions as the simulations, while the simulations resulted around 1650 vehicles/h for a lane closure on a 4-lane motorway. However, from work zone measurements in Borchardt, Pesti et al. (2009), the measured capacities range from 1620 to 1680 vehicles/h. Studies of work zone capacities on two-lane roads with flagger operated traffic control appear to be limited. However, in Shibuya, Nakatsuji et al. (1996) was a microsimulation program developed to analyse flagger controlled work zones, which was validated to measured data. For a flagger operated work zone of a length of 80 m, the resulting capacity was around 600 veh/day/dir. The simulated flagger-operated work zone for 100 m developed in this study resulted in a capacity of around 700 veh/day. It can be concluded that there are deviations in the resulting capacities but that the simulated capacities are similar.

For a comparison of the resulting work zone delays, the procedure in NJDOT (2001) was first applied. The capacity input was based on the HCM equation, while the rest of the parameters were set to be as similar as possible with the respect to the simulations. The prerequisites were a lane closure on a motorway, an AADT of 35000 veh/day and 13 % heavy vehicle ratio. The NJDOT procedure resulted in a total delay of 1320 h/day and the simulations in 2449 h/day. However, using the same procedure based on the methodology presented in Jiang (1999) the resulting delays become 3905 h/day.

5 APPLICATIONS IN PAVEMENT MANAGEMENT

The life-cycle cost tool “Vännen” is a product of an initiative in Sweden to develop a standardized LCC procedure for road investments. The purpose is to promote the use of life-cycle costing in the design phases of the road planning process. Primarily, the tool is a life-cycle cost analysis tool in order to provide the designers with decision support to find the optimal investment alternative from a life-cycle cost perspective. Secondly, it has the purpose to estimate a road investment’s overall future costs. This includes future costs for the pavement, winter maintenance, road equipment, bridge and tunnels. This will help the integration with the long-term-planning tools in order to consider the future costs for a specific road design earlier in the planning process.

5.1 Implementation of the work zone delays in a LCCA tool

One important road user costs to include when performing a LCCA is the work zone delay costs. “Vännen” is a spreadsheet tool in which the resulting work zone delays were implemented in tables. In Figure 4 is the developed graphical-user-interface presented in which the work zone input and maintenance activities can be specified. Based on these inputs, the delays could be computed by fetching the simulation results from the corresponding delay/flow-tables depending on selected work zone configuration, time plan, traffic flows and heavy vehicle ratio. In the case of motorways, the delays for the work zone passing were added analytically. For every maintenance activity during the life-cycle, the net present value of the delay costs can be computed based on the expected delays, valuations of time (VOT) for respective vehicle type and the discount rate.

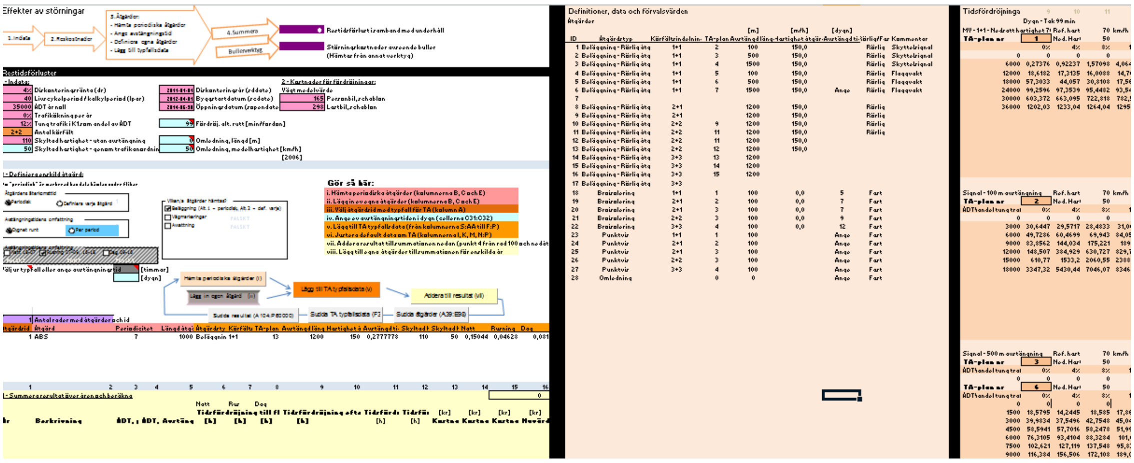

Figure 4: Implementation of the delay/flow-relationships in the Swedish LCC tool “Vännen”

5.2 Application of work zone delay costs in pavement selection

In the selection of wearing course in pavement design for medium traffic flow two-lane roads, a common decision situation is whether to choose a dense-graded hot-mix asphalt (HMA) or stone mastic asphalt (SMA). The pavement module in “Vännen” has therefore been applied to perform a simplified LCCA of the two wearing courses. The purpose was to examine how the inclusion of work zone delay costs influences the decision of pavement type. While the state-of-the-art of LCCA stresses the importance of including all possible road user costs, in this case it was assumed that the other road user costs were equal. In table 1 has the prerequisites for the case study been compiled. In “Vännen” has the life-lengths for different pavement types and traffic flows been estimated based on empirical data and expert judgment. In the tool has also average prices for the pavements been estimated. These were used to perform the LCCA for a case study.

Table 1: Assumed road and work zone properties for the LCCA case study.

Road properties		**Work zone properties**	
Input	**Value**	**Input**	**Value**
Road length	1 km	Work zone type	Flagger control
Speed limit	100 km/h	Speed limit	70 km/h
Number of lanes	2	Work zone length	1 km
Width	9 m	Closure length	1500 m
AADT	7000 vehicles/day	Time	Day time
Heavy vehicle ratio	12 %		
Annual traffic growth	1 %		
Discount rate	4%		
Time period	40 years		

The results from the LCCA (table 2) case study indicate that the SMA has an investment cost that is around 23 % higher than the dense-graded HMA. The better performance of SMA compared to the dense-graded HMA can be addressed to its strong mechanical interlocking of the aggregate minerals (Tashman & Pearson, 2001). In addition, the large proportion of exposed aggregate minerals at the surface provides good wearing resistance. This result in good resistance to both permanent deformations and wearing from studded tires. The improved durability results in lower future costs since fewer maintenance activities are needed, resulting in around 4400 €/km lower maintenance costs for the road administrator. If only the costs incurring for the road operator is considered, the future savings in maintenance costs would not be sufficient to compensate for the higher investment costs. The optimal investment is therefore, if only the road administrator's direct costs are considered, the dense-graded HMA. However, due to the need of more maintenance activities this also results in more traffic disturbances. This scenario therefore results in 19 200 €/km higher delay costs for the road users. In total, the SMA results in 4 600 €/km lower LCC compared to the dense-graded HMA. The SMA therefore becomes the best investment alternative.

Table 2: Estimated life-cycle costs for the two wearing course types.

	Investment Costs (€/km)	Maintenance Costs (€/km)	Work Zone Delay Costs (€/km)	LCC (€/km)
SMA	100 000	160 000	64 000	324 000
Dense- graded HMA	81 000	164 400	83 200	328 600

When work zone delays are included in the LCCA, the LCC become in even higher degree dependent on the traffic situation. This is illustrated in Figure 5, in which the resulting LCCs for a range of initial AADTs have been plotted. The figure also includes the LCCs without the delay costs. In low range AADTs yields the dense-graded HMA the lowest LCC. The differences between including and excluding the delay costs are therefore almost negligible in low traffic flows. The work zone delay costs affect the selection of wearing course in the way that the SMA becomes the preferable investment alternative in lower AADT. If the delay costs are not considered, HMA would be the best alternative up to around 8500 vehicles/day. In the case of including the delay costs, the break-even instead occur around 6000 vehicles/day.

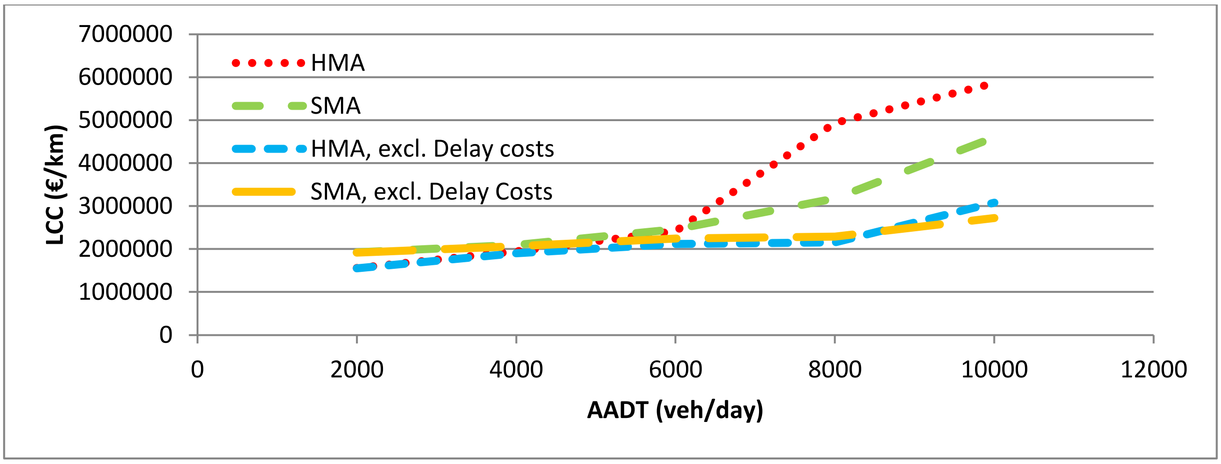

Figure 5: LCCs for two wearing course types when including and excluding the delay costs.

6 DISCUSSION

6.1 Microsimulation's suitability for work zone delay estimations

The selection of microsimulation as a work zone analysis method was based on the need of modelling different road types, work zone types and traffic controls. Microsimulation was considered to be the most appropriate method for this purpose. An advantage of using microsimulation compared to special-purpose work zone analysis methods is that it has been used in many other traffic analysis applications. In this study was no validation performed of the work zone delays compared to traffic measurements. However, a comparison with other work zone studies showed that the capacities of the simulation results are similar, even though the studies indicate large deviations in work zone capacities. A comparison of the delays between different work zone traffic analysis tools resulted in a difference of 1130 h/day between the maximum and minimum estimations. Using the delay estimation from this study resulted in 2449 h/day. This is slightly below the average (2613 h/day) of the two other methodologies. Without actual traffic measurements of the delays it is not possible to verify the most accurate delay estimation method. However, considering that the simulation result is around average, microsimulation's high level of traffic representation and calibrations/validations in normal conditions, it provides some confidence in the results.

During this study several issues related to the application of the methodology has been identified. One issue is since microsimulation is computationally heavy; all simulations have to be simulated in advance in order to become user friendly. Considering all different road types, work zone types and traffic compositions, the number of possible combinations became large. In this study, this was partly solved by programming scripts to automate the simulation processes. Nevertheless, the number of combinations had to be limited. For example, different designs of the work zones were not considered. This unfortunately blurs microsimulation's advantage of having a high level of detail in the traffic representation. Another great limitation was to only model a corridor and excluding diversion delays. This assumption results in that the model is less applicable in urban areas where there usually are several alternative roads with acceptable capacities. In rural areas is the number of alternative roads limited; therefore are the estimated delays probably more reliable there than compared to urban areas. However, using the delay/flow-relationships it could be possible to implement the work zone delays in macrosimulation models to assess the network effects.

The estimated number of replications for the simulation was based on a trade-off between statistical significant results in low AADTs (few data points) and simulation time. In the work zone models for motorways were only the part upstream of the work zone modelled. This simplification was based on the need to able to calculate the work zone delays for an arbitrary length. In lower traffic volumes is the probability of conflicts between the vehicles small, therefore are the delays mainly affected by the reduced speed limit in the advance warning area. The number of replications used in this study resulted in no significant delays in low traffic flows. In this case, the deviations in the delays therefore limit some of the benefits of using microsimulation's high level of detail. If the simulation time is not a problem then this could simply be solved by estimating the number of needed replications based the necessary level of detail. Another solution would be to adapt the number of replications to the current traffic flows.

6.2 Road user cost considerations in pavement management

The simulation results were implemented in an LCCA tool, which was used to perform the case study for the selection of wearing course type. This in order to complement the conventional life-cycle cost components; investment, operation and maintenance cost. The case study indicated that the work zone delay costs become an important aspect in the selection of the wearing course with the lowest LCC. The delay costs accounted for over 25 % of the total LCC for the case with a dense-graded HMA course. If only the road administrator's cost would be included and the road has an AADT of 7000 vehicles/day, then the best investment alternative is the HMA. However, if the road user costs are included in the analysis then the SMA would be the best choice. This since the pavement type is more durable than the dense-graded HMA, which reduces the necessary maintenance activities, hence also the impact on the road users. This example also tells a difficulty in life-cycle cost analyses, whether the road operator should include road user costs or not in the analysis. The SMA would be the optimal alternative from the road users' point of view. However, from the road operator's perspective the HMA would be a better alternative. A higher investment cost burden is placed on the road administrator, while the benefits appear the road users. Nonetheless, road user costs are important to consider for public organizations in order to maximize the benefits for the tax payers.

7 CONCLUSIONS

The use of microsimulation to estimate work zone delays has been examined. The method's high level of detail gave the opportunity to model work zone of various types, road types and traffic compositions. However, during the study several issues have been identified when using the simulation results in applications for work zone management. One of them was that a large number of simulations had to be run in advance in order to be able to implement it in user-applications for work zone and pavement management. This results in that the method becomes less adaptable to changing conditions. Consequently, this partly blurs microsimulation's main advantage of having a high level-of-detail in the representation of traffic flows. The LCCA spreadsheet tool "Vännen" was used to perform a LCCA in a case study for pavement selection in which the work zone delay costs were included. The case study indicated that work zone delay costs become important in finding the optimal alternative from a life-cycle perspective. By including the work zone delay costs already in design phase of roads and pavements, the future road user costs can be minimized. In addition to improved work zone scheduling, this may be an important measure to tackle the impacts of work zones and decrease road users' annoyance concerning congestions.

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