A METHODOLOGY FOR ADDRESSING USER COSTS WHILE PLANNING PAVEMENT REHABILITATION INTERVENTIONS IN HIGHLY TRAFFICKED ROADS

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ABSTRACT

Making decisions regarding pavement maintenance planning involves several issues. This paper describes a methodology developed to support decisions where there are multiple objectives to be satisfied within this context. Those objectives are, usually, agency cost minimisation and pavement quality maximisation. However, the concerns for road user effects, could take to the inclusion of other objectives such as the minimisation of user costs. This type of costs is particularly relevant when analyzing upper hierarchy road segments where the traffic levels are higher and the chances of traffic disruptions occur at work zones are also higher. The methodology presented in this paper was developed specifically to allow a reliable way to include road user effects in the decision-making process, including them as attributes of the alternatives, as in a multi-criteria analysis basis. Using as case study the intervention in an urban motorway, several alternatives where compared considering attributes such as works' duration and travel time increase in addition to, of course, agency cost. The appraisal of the available alternatives using the proposed methodology allowed a more systematic comparison and decision between them, confirming this procedure as a valid way of addressing different and divergent objectives.

Keywords: pavement, maintenance and rehabilitation, user costs, work zone

INTRODUCTION

In the context of pavement management, important progress has been made with regard to user costs in the last 15 years. Research in this subject has tried to develop tools that can generate, on the one hand, the pavement preservation plan with the minimum cost given a certain condition level and, on the other, the plan that results in the best pavement condition for a maximum available budget.

A common issue regarding pavement preservation is how to address multiple objectives within the decision-making process. Generally, those objectives are agency cost minimisation and pavement quality maximisation. However, the concerns for road users should include other objectives, such as the minimisation of the traffic disruption at work zones. Several methodologies have been developed to estimate a monetary cost associated to those effects and, in such cases, adding it to the agency cost is a common practice.

Another important question is the level of pavement management under analysis. Several issues that are relevant for a network level decision won't be for a project level decision. Regarding road users, in network level perspective, the pavement functional condition (roughness, skid resistance, etc.) could be one of the most relevant issues (Uddin, 2006). However, when planning a project level intervention, the decision-maker should know that users' most significant concerns are related to the intervention impact on traffic flow and its effects such as travel time delay.

The present work described intends to provide a model that can estimate accurately the agency cost for a given pavement intervention, as well as other attributes of that intervention related to effect that roadwork has on road users. The main difference from the implemented methodologies is the fact that road-user effects are included in the decision-making process as attributes of the alternatives, instead of computing a monetary cost. This approach will allow the decision-maker to consider the analysis of an intervention as a multiple-criteria decision-making process. Two main advantages can be identified in this approach. In cases where very high levels of traffic exist, the calculation of user cost produces values far higher than the agency cost, as a result of the magnitude of the delays experienced by users (Haas, 2001), altering the main purpose of the process. This should not imply the omission of user costs but rather the need to weigh them in the final assessment, in such a way that the decision-maker considers adequate (Hall et al., 2003). Hence, the adoption of a multiple-criteria decision-making process can avoid situations such as those above, also permitting the decision-maker to define the weight that each attribute should have in the final assessment.

Another factor supporting the abovementioned option for multiple-criteria decision-making is the flexibility to address different priorities based on the characteristics of each intervention. Site and project features, traffic volume, road hierarchy and role in the network clearly should be taken into account.

The proposed model is meant to be used in the context of pavement management but in such a way that the intervention to take place is already defined, thus focusing the analysis on the way in which it is planned and developed. This paper focuses mainly on determining attributes instead of the subsequent decision-making process. A brief literature review is presented below, mainly focusing the state-of-the-practice of user costs inclusion within pavement management as well as work zone analysis.

USER COSTS WITHIN PAVEMENT MANAGEMENT

In general, existing literature presents user costs in three categories: vehicle operating costs (VOC), user delay and accident costs. VOC include costs such as fuel, oil, tyres, maintenance and repair, and depreciation. User delay costs are a result of travel time and the monetary value of each hour spent in transit. Finally, accident costs are based on accident rates and the monetary value associated to each type of accident. User costs also can be analysed from the moment when costs are incurred by users (i.e., during roadworks or in normal operating conditions). In the context of pavement preservation, user cost analysis tends to focus on maintenance and rehabilitation interventions where the users' perception of cost is higher.

Existing methodologies include the estimate of user costs associated to a specific maintenance or rehabilitation intervention, based on inputs relative to the intervention (e.g., work zone layout, capacity and permitted speed) and the traffic characteristics. For instance, the Federal Highway Administration (FHWA) methodology, based on the abovementioned factors, analyses traffic flow conditions at the work zone (free flow or forced flow) and then computes the delays (which are subsequently converted into a monetary cost) as well as the VOC relative to the expected speed change cycles (Walls and Smith, 1998). The well-known Highway Development and Management Model (HDM) comprises a simulation model called ROADWORK which is able to calculate the additional time and fuel consumption due to the presence of a work zone (Bennett and Greenwood, 2003). As in the FHWA method, the analysis is performed for either traffic conditions, with or without queued vehicles. Other methodologies, such as QUADRO (Queues and Delays at Roadworks) of the Department for Transport (DfT, 2006) which includes VOC and accident costs besides user delay, and QUEWZ (Queue and User Cost Evaluation for Work Zones) of the Texas Transportation Institute (Copeland, 1999) which includes user delay and emissions, were also developed to address the specific issue of user costs due to the presence of work zones.

The mentioned methodologies show that there is a significant attention to the issue of user effects at project level pavement management. Given the high traffic flows that exist in nowadays road networks and bearing in mind the user effects specifically related to roadworks, work zone analysis is also an active field of research. Besides the estimation of those effects, several advances have been achieved regarding its inclusion in the decision process. The following section summarizes the main contributions of the last years in what it concerns to the developments of work zone analysis tools.

WORK ZONE ANALYSIS

The analysis of work zones can considered as a dilemma involving three different players: highway agencies, road users and contractors (Najafi and Soares, 2001). Each one has different objectives and priorities regarding its role. Agencies try to minimize construction cost and users' delay, assuring safety to drivers and construction workers. The road users seek for quality in the roadway and driving without delays. These different objectives were at the basis of several advances that tried to integrate them in a single decision process.

Work zone optimal length has been subject to various studies where the total intervention cost is minimised. Martinelli and Xu (1996) developed a model that is able to find the optimal length for four-lane divided freeway work zones, including construction, delay and accident costs. Schonfeld and Chien developed optimisation procedures for work zone lengths for two-lane two-way highways (Schonfeld and Chien, 1999) and for four-lane highways (Chien and Schonfeld, 2001) including construction and user delay costs. Tang and Chien (2008) worked also on a model where the work zone schedule was optimised by minimising total cost (agency and user costs such as VOC, delay and accident costs).

Besides optimisation procedures, simulation models were also developed to access the impact of work zones. QuickZone and CA4PRS are two simulation models specifically designed to work zone analysis. Developed by FHWA and Mitretek Systems, QuickZone is a work zone simulation tool, being its main functions the quantification of delay resulting from capacity decreases in work zones and, among others, the support of trade-off analyses between construction costs and delay costs (TFHRC, 2001). CA4PRS (Construction Analysis for Pavement Rehabilitation Strategies) was developed for California's Department of Transportation (Caltrans) as a management tool for the rehabilitation and reconstruction of highways. It allows the estimation of the maximum probable length of highway pavement that can be rehabilitated or reconstructed given various project constraints (Lee and Ibbs, 2005). While QuickZone is mainly meant for user effect estimation, CA4PRS also considers construction process matters such as contractors' resource allocation, materials curing time, etc. Other traffic micro-simulation models have also been used in the context of work zone analysis.

The mentioned methodologies and tools show that pavement management, particularly while planning work zones (project level management) deserve an integrated approach given the different and complex issues involved, especially when in the presence of high traffic flows where multiple intervention options appear and several constraints exist.

PROPOSED METHODOLOGY

Scope

For a given pavement management system output (or the need for intervention as a result of a site survey), the definition of the maintenance treatment to be carried out constitutes an input to the model, along with traffic and other site features. The model intends to generate a set of feasible options concerning, for example, working plant layouts and schedules, and combine them in order to include all the options in the intervention's planning and undertaking.

As model outputs, the attributes for each feasible alternative are calculated in order to be used subsequently in the multi-criteria decision-making process. This method is to be used in the appraisal of interventions high traffic roads where divergent objectives (e.g., the minimisation of agency cost for the intervention and the minimisation of the intervention's effect on the users) can arise.

Framework

Figure 1 describes the layout supporting the proposed model. As noted earlier, the inputs consist of a fully described pavement intervention, traffic characterisation and all relevant site and project constraints. The intervention description includes all the activities necessary (e.g., site preparation, existing pavement milling, placement of new layers, etc.) and work quantities involved. Traffic characterisation includes daily traffic volume; hourly, weekly and monthly variation; traffic composition (percentage of light and heavy vehicles) and average vehicle speed. By site and project constraints, we mean any relevant constraint that could restrict, from the beginning, the feasible set of alternatives.

The variables module, described below, is the main source of variation allowing the model to generate different alternatives based on different work schedule policies and different work zone layouts. Each activity's duration is calculated by considering the necessary quantity of work and the expected productivity for a chosen work zone layout. The estimated cost of each activity depends on the schedule policy selected, and is computed using the activity's unit cost. The cost and the duration, estimated for each activity, relies on the unit costs database (containing the unit cost for each activity and for each work schedule) and on the productivity database (where, depending on the work zone layout, productivity values are available for each activity), respectively.

The model outputs are three different attributes intended to characterise each alternative by cost (supported by the agency), total works' duration and average delay that users face.

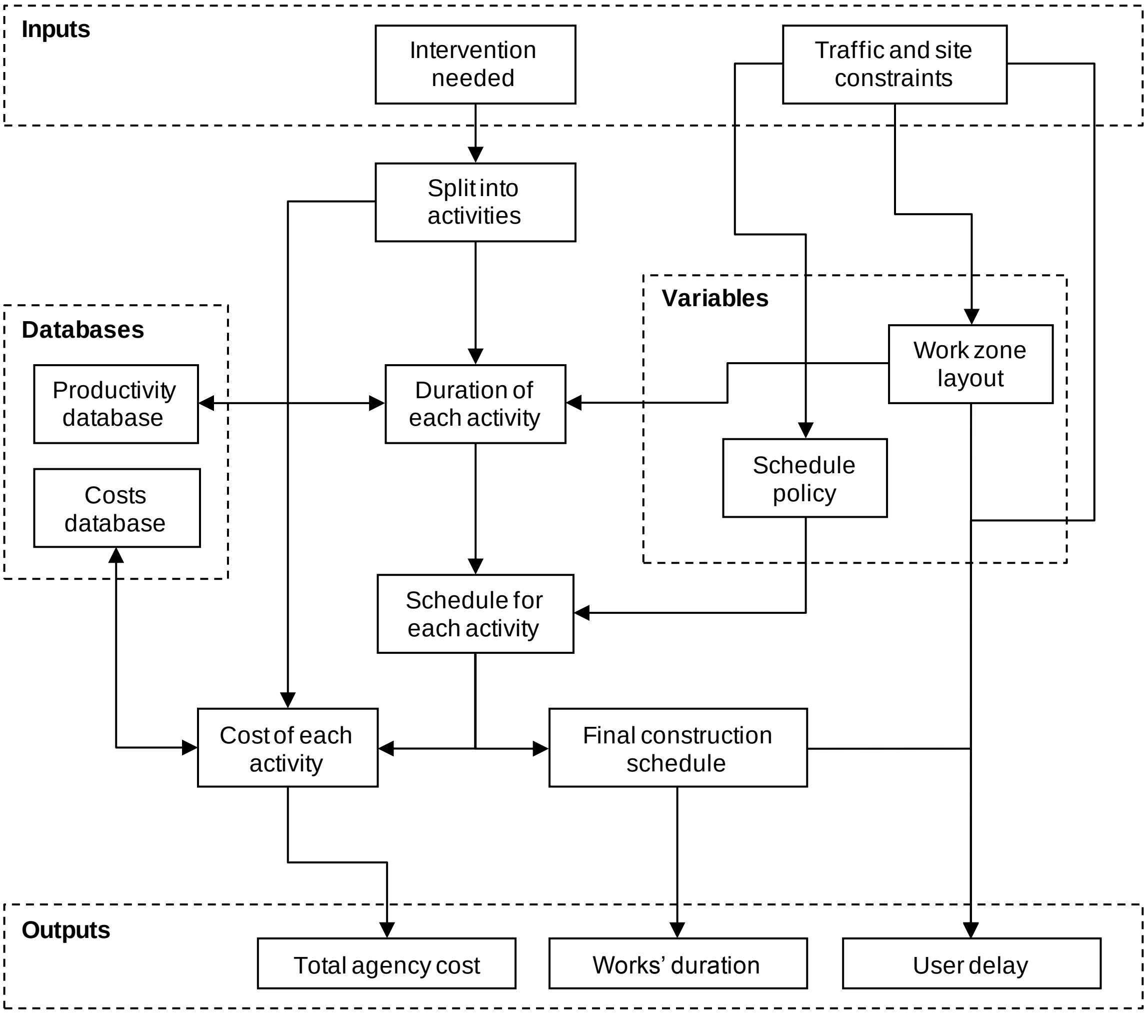

Figure 1 – Simplified model layout

Variables

As previously mentioned, the variables module is the main source of variation allowing the model to generate different alternatives for the intervention, corresponding in each case to a specific schedule policy and a possible work zone layout. For both issues, all the relevant options are considered and the model generates the set of all feasible options for the intervention.

Regarding work zone layout and depending on the road type and other constraints, the number of lanes affected by the intervention, different work zone lengths and traffic management schemes can be tested. Table 1 shows the potential options for the different features related to work zone layout.

Table 1 – Work zone layout related options

Feature	Options
Work zone character	Short-term Long-term
Carriageway analysis	One way intervention Two way intervention (with traffic shifting to the opposite direction)
Number of simultaneous work zones	1 2 Multiple
Longitudinal closure pattern	Full length closure Partial length closure
Lane reduction	n to n-1, n to n-2, … Full closure Other
Work zone length	Fixed (by regulation) Fixed (by most economical option) Function of the available time frame and productivity (in short-term work zones)

In respect to schedule policy and, taking into account the growing awareness for the minimisation of traffic disruptions due to roadworks all potential work schedules are tested. This analysis includes, for instance, daytime work with no restrictions, daytime work in the off-peak period, night-time or weekend work only, etc.. Moreover, monthly traffic variations can be considered to generate different intervention options (i.e., performing pavement maintenance interventions during the summer when traffic flows are lower). Specific site and project constraints could clearly determine if those different alternatives are not feasible, excluding them from the analysis.

Attributes

The selection of the attributes for each alternative generated by the model was based on the need for the results to be sufficiently representative of the issues involved. Agency cost is naturally the first choice and the most relevant attribute. Its importance is only equalled by other attributes in locations characterised by high traffic flows. The other two attributes – total works' duration and average user delay – both related to the effects that users will have to face, were chosen in order to measure distinct aspects. Total works' duration aims to evaluate how long users will have to face traffic disruptions caused by roadwork; the average user delay is an indicator of the magnitude of those disruptions in terms of increase in travel time due to the presence of the work zone. The total works' duration is a direct model output. However, the average user delay involves a more complex calculation, which could be based, for instance, on the FHWA methodology for user delay (Walls and Smith, 1998) or any other of the ones presented before. As can be seen in Figure 1, the average user delay will depend on the work zone layout, the estimated traffic flow and the chosen construction schedule.

CASE STUDY

Description

In this part of the paper a single intervention on a road segment of an urban motorway in the Portuguese context (Lisbon Metropolitan Area), with high traffic flows is described. Based on two different daily traffic flow distributions (both obtained from inbound segments of Lisbon urban motorway system) and cross-section geometry (Table 2), we examine an intervention concerning the placement of a new asphalt wearing course (for the entire width of the carriageway) and removal of the previous one. Several scenarios will be analysed by using the previously described model. The segment length is 2700 meters and the cross-section has three lanes on either side, plus a hard shoulder. There carriageways are separate, with a concrete removable barrier between them.

Table 2 – Cross-section details

Parameter	Value
Lanes (in each direction)	3
Carriageway width (m)	13.50
Lane width (m)	3.50
Right shoulder width (m)	2.50
Left shoulder width (m)	0.50
Speed (km/h)	90
Capacity (vphpl)	2200

The capacity per lane was calculated following the Highway Capacity Manual 2000 methodology (TRB, 2000).

The intervention (asphalt wearing course replacement in 4 cm depth and previous layer milling) under study was split into five activities (Table 2) in order to analyse cost and productivity. Clearly, other activities are necessary for this type of intervention (e.g., tack coat placing, construction joint sealing, final road marking, etc.) but they were excluded from the analysis. The activities' costs were derived from inquiries made to several contractors and road infrastructure concessionaires with exception to activities 1 and 5 (traffic management scheme implementation and removal). For both, it was assumed that they could lead to an increase in the amounts for the other activities (i.e., milling, paving and temporary road marking): 3% for activity 1 and 2% for activity 5. In terms of productivity, several inquiries were also made to contractors and road infrastructure concessionaires.

Table 3 – Activities, costs and productivities

Activity	Average cost		Average productivity
	Day (week)	Night or weekend	
1 – Traffic management implementation	22.71 €/100m^2	31.71 €/100m^2	2h00 /work period
2 – Milling (4 cm)	2.50 €/m^2	3.50 €/m^2	600 m^2/h
3 – Wearing course placement (4 cm)	4.80 €/m^2	6.70 €/m^2	800 m^2/h
4 – Road marking	0.27 €/m^2	0.37 €/m^2	1h00 /work period
5 – Traffic management removal	15.14 €/100m^2	21.14 €/100m^2	1h30 /work period
Total	7.95 €/m^2	11.10 €/m^2	-

In what it concerns traffic flow, hourly distributions were computed for weekdays and weekends based on one complete month (March 2009) for two road segments within the urban motorway system of Lisbon Metropolitan Area, using the data provided from the automatic traffic counters. These segments comprise high traffic flows, the first one with an average week daily traffic of over 140,000 vehicles (traffic distribution I) and a second one with 110,000 vehicles (traffic distribution II). Tables 4 and 5 show these distributions for the inbound direction. A homogenisation factor of two was used to convert trucks to passenger cars.

Table 4 – Hourly average traffic flows for weekdays and weekend (traffic distribution I)

Hour	Weekday	Weekend	Hour	Weekday	Weekend
0h - 1h	782	1418	**12h - 13h**	3947	3551
1h - 2h	276	715	**13h - 14h**	3895	3254
2h - 3h	242	588	**14h - 15h**	4386	3561
3h - 4h	221	426	**15h - 16h**	4186	3939
4h - 5h	344	396	**16h - 17h**	4198	3796
5h - 6h	763	534	**17h - 18h**	5183	4097
6h - 7h	3059	1040	**18h - 19h**	5185	4157
7h - 8h	4642	1869	**19h - 20h**	4333	3634
8h - 9h	3933	2423	**20h - 21h**	3194	2629
9h - 10h	4258	3014	**21h - 22h**	2268	2043
10h - 11h	4305	3081	**22h - 23h**	1821	1976
11h - 12h	4036	3182	**23h - 24h**	1494	1645
			Total	**70951**	**56968**

Table 5 – Hourly average traffic flows for weekdays and weekend (traffic distribution II)

Hour	Weekday	Weekend	Hour	Weekday	Weekend
0h - 1h	832	1320	**12h - 13h**	3088	2828
1h - 2h	284	629	**13h - 14h**	3211	2748
2h - 3h	189	475	**14h - 15h**	3603	2817
3h - 4h	137	322	**15h - 16h**	3480	3351
4h - 5h	163	289	**16h - 17h**	3615	3060
5h - 6h	279	301	**17h - 18h**	3729	2909
6h - 7h	783	430	**18h - 19h**	3549	2850
7h - 8h	2781	847	**19h - 20h**	3395	2764
8h - 9h	4224	1254	**20h - 21h**	3234	2325
9h - 10h	3995	1850	**21h - 22h**	2324	2091
10h - 11h	3273	2323	**22h - 23h**	1677	1673
11h - 12h	2824	2436	**23h - 24h**	1292	1424
			Total	**55961**	**43316**

Scenarios

In order to generate the intervention scenarios, two assumptions were made. At first, the complete closure of the road segment was not considered as an option since a network analysis model was needed to assess it. In terms of the number of simultaneous work zones, it was assumed that, due to contractors' resources constraints, only one work zone could be in place at any given.

There were considered to possible work zone layouts in order to represent the typical options available. One option, work zone layout A (see Figure 2), refers to lane reduction (3 to 2 lanes) affecting only the inbound direction. It comprises two stages: at first the work occurs in the left side of the carriageway (half of the width) keeping two open lanes in the right (using the hard shoulder width); then the opposite situation is set up. Subsequently, the sequence is repeated until the whole road segment is completed.

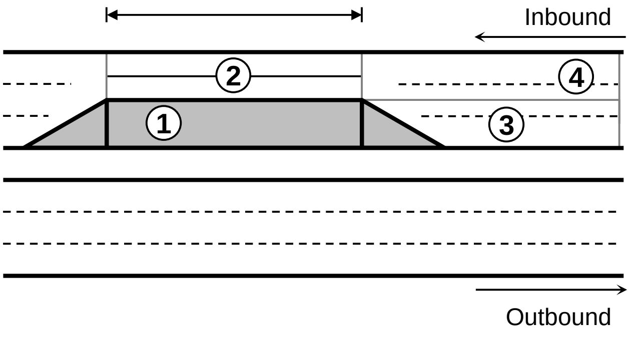

Figure 2 – Work zone layout A

In work zone layout B (Figure 3), the whole inbound direction traffic is shifted to the opposite direction. Outbound traffic is also affect and the layout is set up for the entire segment length (2700 m). Two lanes are available for both directions (see Table 6).

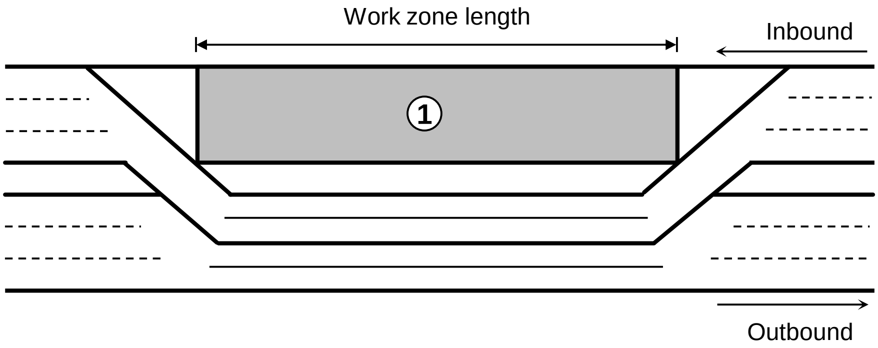

Figure 3 – Work zone layout B

Further analysis of the traffic flow behaviour in the work zone requires the estimation of the speed adopted by drivers, as well as work zone capacity. Resulting from empirical studies or relying on traffic flow theory, several methods are available to estimate those speeds and capacities. Using the methodology developed by Benekohal et al. (2004) and given the geometry of the open lanes and lateral clearance, the speed adopted by drivers when traversing the work zone was calculated. The capacities (vehicle per hour) for layout A (stages 1 and 2) and for work zone layout B were obtained using Figure 4 which reproduces the Highway Capacity Manual (1994 edition updated in 1997). Choosing a probability factor of 85% and considering this type of lane reduction (3 to 2 lanes), Figure 4 provides the expected capacity (vehicles per hour per lane).

Table 6 – Work zone layouts description

Layout	**A**		**B**
	Stage 1	**Stage 2**	**Single stage**
Work side	Left	Right	Opposite direction
Lanes open (in each direction)	2	2	2
Carriageway width (m)	6.10	6.10	13.50
Lane width (m)	2.90	2.90	3.00
Right shoulder width (m)	0.15	0.15	0.20
Left shoulder width (m)	0.15	0.15	0.20
Paving width (m)	6.75	6.75	13.50
Barrier width (m)	0.60	0.60	0.70
Speed (km/h)	60	60	60
Capacity (vphpl)	1470	1470	1470

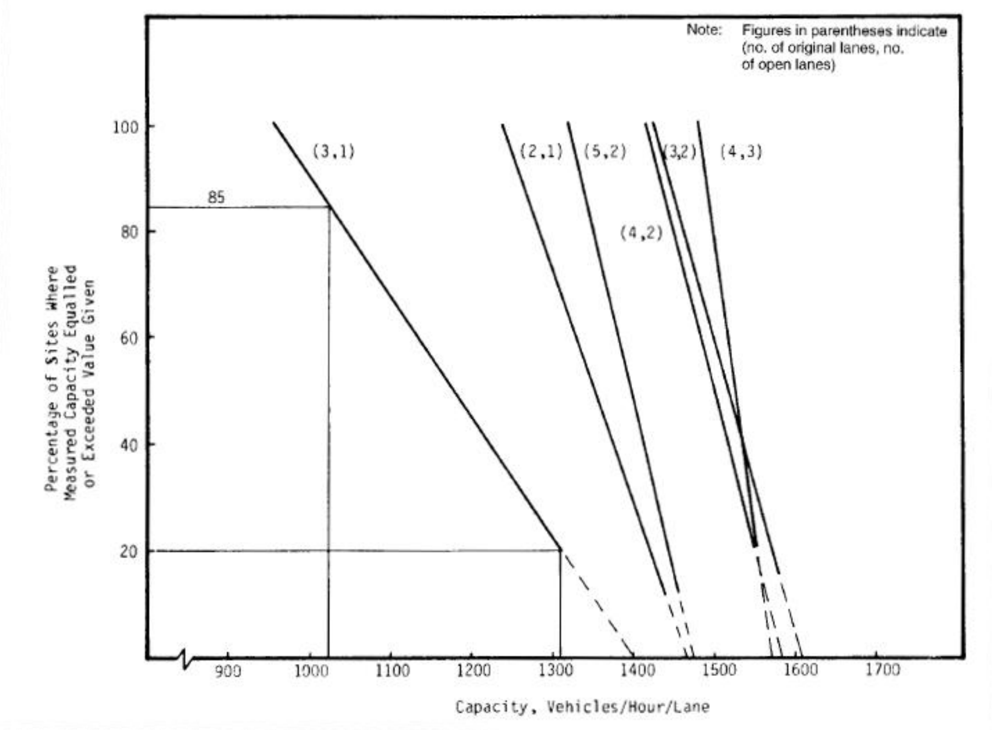

Figure 4 – Cumulative distribution of observed work zone capacities (HCM, 1997)

Figures 5 and 6 include the hourly average traffic flows (weekday and weekend) previously presented in Table 4 and 5, as well as the work zone capacity, for both distributions.

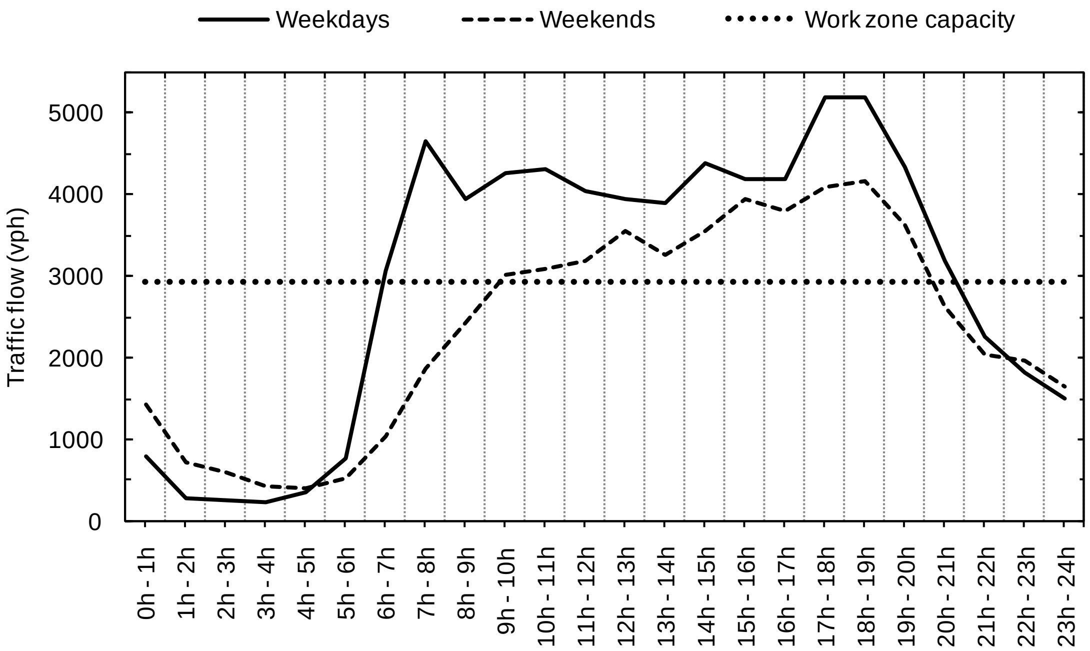

Figure 5 – Hourly average traffic flows (weekday and weekend) and work zone capacity (traffic distribution I)

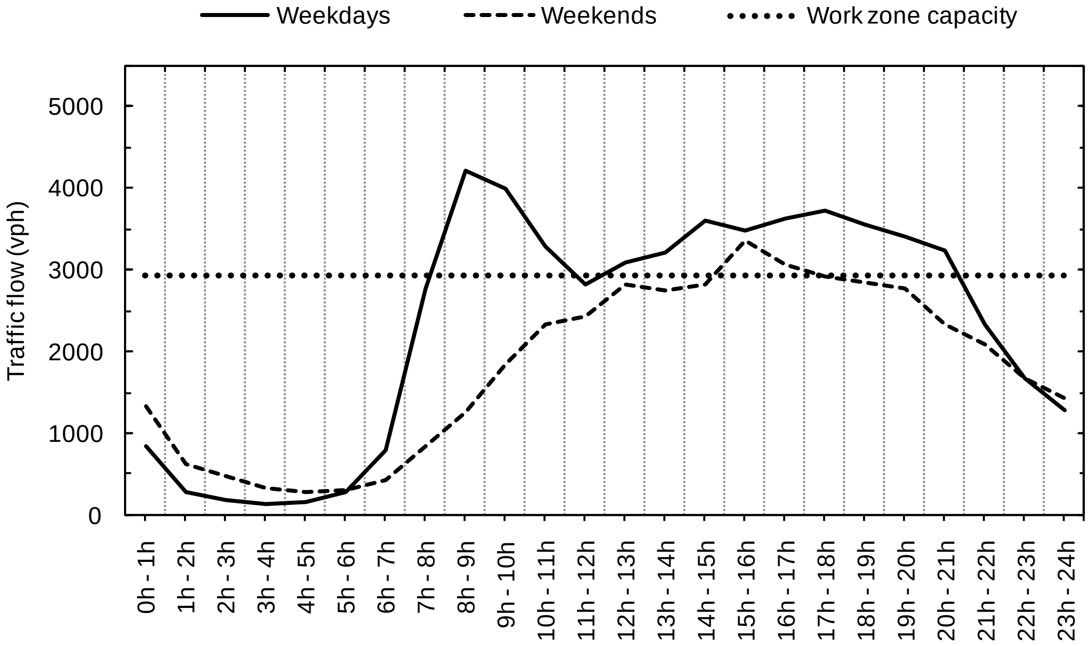

Figure 6 – Hourly average traffic flows (weekday and weekend) and work zone capacity (traffic distribution II)

For distribution I it is visible during weekdays the morning and evening peak and also a significantly high traffic flow during the day between peak periods. During weekends, high traffic flow also exists during the afternoon and evening. For distribution II, being the traffic flows lower, the morning peak is clearly visible and there is no significant evening peak which is a common situation for inbound traffic in urban areas. Given the high traffic flows, night-time and weekend work were preferred and subject of analysis. For traffic distribution II, week day work in the off-peak period seams also a feasible option. From traffic distributions analysis, Table 7 contains the allowed schedule policies to be tested.

Table 7 – Permitted schedules policies (from traffic distribution analysis)

		Traffic distribution I	**Traffic distribution II**
Week	**Day**	No	Off-peak only
	Night	Yes	Yes
Weekend	**Day**	Off-peak only	Yes
	Night	Yes	Yes

Five different alternatives where studied in order to allow the comparison of both work zone layouts and different work schedules (see Table 8). Alternatives 1, 2 and 3 consider traffic distribution I and alternatives 4 and 5 are related to traffic distribution II. The described combination of layouts and schedules is meant to turn out in considerably different alternatives in what it concerns to attributes, illustrating the methodology's use. However, other alternatives could be considered.

Table 8 – Work schedules for each alternative

Traffic distribution	Alternative	Layout	Week	Weekend
I	1	A	21:00 to 6:00 (9h)	21:00 to 6:00 (9h)
	2	A	21:00 to 6:00 (9h)	21:00 to 15:00 (18h)
	3	B	-	21:00 to 15:00 (18h)
II	4	A	10:00 to 19:00 (9h)	-
	5	B	-	Fri. 21:00 to Mon. 6:00 (57h)

Alternative 1 comprises exclusively night-time work every day of the week. Alternative 2 is similar but daytime work is allowed during Saturday and Sunday, being operated in two consecutive 9 hour shifts. Alternative 3 (considering work zone layout B), consists of two work periods each week, from Friday 21:00 to Saturday 15:00 and in the same schedule for Saturday night to Sunday afternoon. Given the lower traffic flows for distribution II, alternative 4 consists of daytime work during the week in the off-peak period and for alternative 5 a one-time construction of the whole road segment length (2700 m) during the weekend (57 h consecutive closure), taking advantage of the wider work space available that leads to higher productivity in layout B.

Estimating attributes

For the five considered alternatives, several attributes were calculated regarding cost, works' duration and user delay.

At first, given the available time frames for each scenario and the productivity of each activity, the maximum length that each work zone can achieve was estimated (Table 10). Milling was considered critical since its productivity is lower than paving. For layout A (both stages), we used the rate of 600 m^2/hour (average) and a rate of 800 m^2/hour for layout B, due to the wider space available.

For construction cost estimates, the labour cost was assumed to represent 20% of the total construction cost and every time two consecutive work shifts take place, a 100% increase in labour costs is included, representing the need for another work crew.

Table 9 – Baseline values for productivity and costs

Parameter	Value
Average milling productivity (half carriageway)	600 m^2/h
Milling productivity (whole carriageway)	800 m^2/h
Labour cost % (percentage of total cost)	20%
Increase in labour cost for consecutive shifts	100%

Table 10 – Work zones length calculation

Layout	**A (half carriageway)**		**B (whole carriageway)**	
Type of closure	**9h**	**18h**	**18h**	**57h**
Available time frame	9h00	18h00	18h00	57h00
Milling productivity (m^2/h)	600	600	800	800
Max. paving length per hour (m)	90	90	60	60
Milling + paving duration	4h30	13h30	13h30	52h30
Work zone length (m)	405	1215	810	3150

Table 11 – Costs for each type of closure

Layout	**A**			**B**	
Type of closure	**9h**	**9h**	**18h**	**18h**	**57h**
Schedule	**Day**	**Night**	**Weekend**	**Weekend**	**Weekend**
Work zone length (m)	405	405	1215	810	3150
Paving width (m)	6.75	6.75	6.75	13.50	13.50
Cost (€/m^2)	7.95	11.10	11.10	11.10	11.10
Labour cost	20%	20%	20%	20%	20%
Penalty for two consecutive shifts	0%	0%	100%	100%	100%
Cost (€/closure)	21,733 €	30,345 €	109,241 €	145,654 €	566,433 €

Table 12 – Cost and works' duration for each alternative

Traffic distribution		**I**		**II**	
Alternative	**1**	**2**	**3**	**4**	**5**
Layout	A	A	B	A	B
Schedule policy	9h night-time closures	9h night-time closures and 18h weekend closures	18h weekend closures	9h weekday off-peak closures	57h full weekend closures
Total cost (€)	404,595 €	441,009 €	485,514 €	289,778 €	485,514 €
Duration (h)	120	102	60	120	49
Duration (work days)	14	10	4	14	2

Table 11 shows the closure cost for each type of schedule and duration. Given the length of road that corresponds to each closure and the number of closures needed, the total intervention construction cost can be computed as well as duration.

Table 12 includes the calculation of the agency cost and duration attributes for the appraisal of the abovementioned alternatives. In terms of duration, given the length of the work zone, an estimate was generated for the number of working days (considering the permitted schedules) necessary to complete the intervention.

The delay calculation was made following the FHWA methodology (Walls and Smith, 1998) based on the possible traffic conditions: free flow or forced flow with the queue formation. Figure 7 shows the speed change cycles in the base of traffic delay calculations (for the forced flow condition).

For instance, in alternative 1, since all the work takes place during night-time (from 21:00 to 6:00), there isn't any moment where the traffic demand is higher than the work zone capacity (see Figure 5). In this case, the users' delay comes exclusively from the need to travel at lower speed in the work zone and from the associated speed change cycle (travelling at 90 km/h, decelerating to 60 km/h, traversing the work zone at 60 km/h and then accelerating back to 90 km/h). For the other 4 alternatives, the work zone capacity is exceed in some period. In these cases, there will be queue formation and the total delay comprises the time at the queue travelling at a lower speed (level of service F), the time traversing the work zone and the speed change cycle delay.

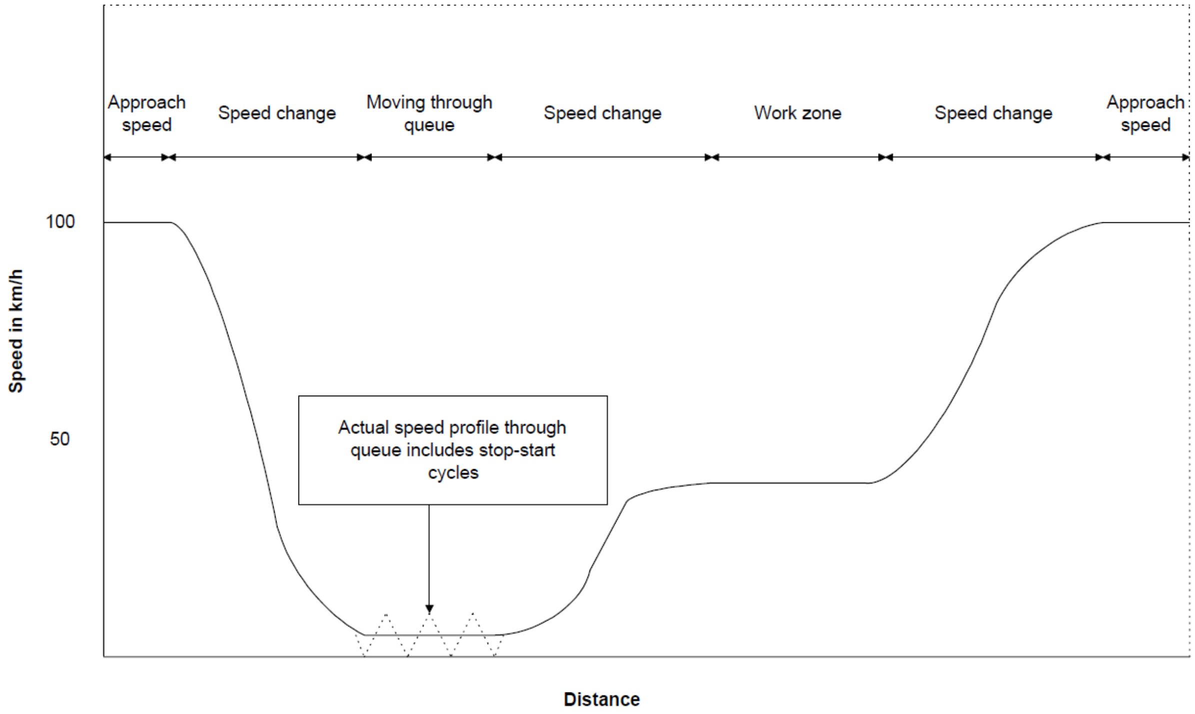

Figure 7 – Speed change cycles due to the presence of a work zone (Bennett and Greenwood, 2003)

For the traffic analysis and subsequent delay calculations following the FHWA methodology, several assumptions were made as shown in Table 13. Since there is no network traffic analysis it is not possible to estimate the change in traffic flows when drivers are aware that there is a work zone. However it is authors' believe that traffic demand will probably decrease in those periods, depending, obviously, on the prior information given to users as well as trip purpose. It was assumed a 10% reduction during weekdays and a 5% reduction during weekends (where drivers could be less familiar with the presence of a work zone). This type of reduction is due to "no show" traffic plus detour traffic (Lee et al., 2005).

Table 13 – Baseline values for user delay calculations

Parameter	**Value**
Weekdays traffic reduction	10%
Weekends traffic reduction	5%
Speed limit under normal operating conditions (km/h)	90
Lanes in each direction during normal conditions	3
Free flow capacity (vphpl)	2200
Work zone speed limit (km/h)	60
Lanes open in each direction during work zone	2
Work zone capacity (vphpl)	1470

Table 14 shows the traffic analysis results following the FHWA methodology. It was computed the queueing duration, maximum delay and maximum queue length (showing the corresponding period when it occurs). There was also calculated the amount of traffic that would be forced to traverse a work zone and the delay due to the work zones.

Table 14 – User delay for each alternative

Alternative	**1**	**2 and 3**	**4**	**5**
Situation	Week nights	Weekends	Weekdays	Weekend
% daily traffic facing speed reduction	4%	56%	58%	100%
% daily traffic facing queuing	0%	28%	42%	22%
Queueing duration (h)	No queue	5 (11:00 - 16:00)	6 (14:00 - 20:00)	3 (15:00 - 18:00)
Max. delay (min)	<1	19 (14:00 - 15:00)	29 (18:00 - 19:00)	5 (16:00 - 17:00)
Max. queue length (km)	No queue	8.9 (14:00 - 15:00)	13.3 (18:00 - 19:00)	2.2 (16:00 - 17:00)

Figures 8, 9, 10 and 11 illustrate the results presented above. For each alternative it is plotted the work zone existence and capacity, traffic demand, average delay and queued vehicles where applicable.

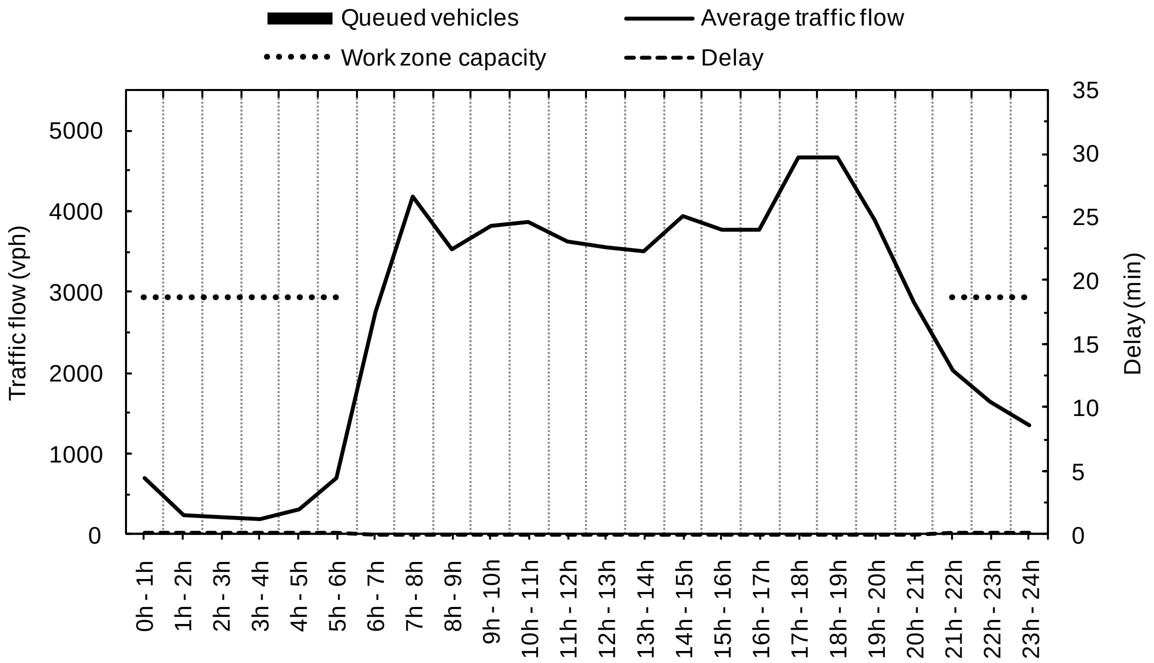

Figure 8 – Number of queued vehicles and average hourly delay for alternative 1

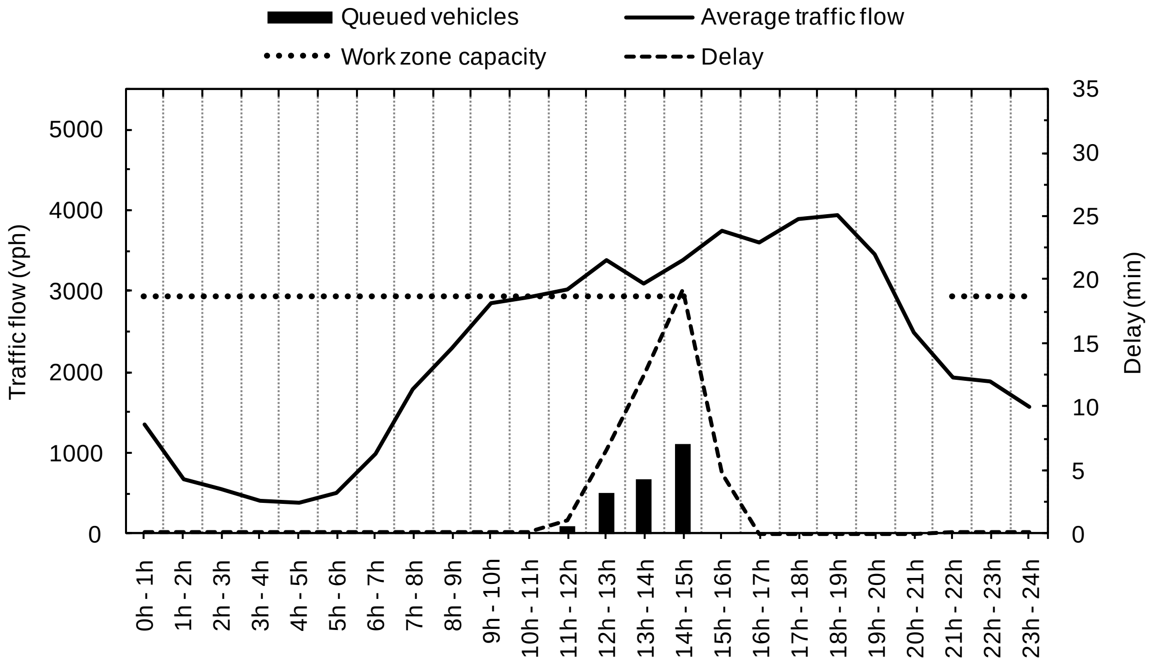

Figure 9 – Number of queued vehicles and average hourly delay for alternatives 2 and 3

Alternative 2 is similar to alternative 3 during the weekend (same schedule) and to alternative 1 during the week nights. Thus, the worst case for it will be the same of alternative 3 (weekends).

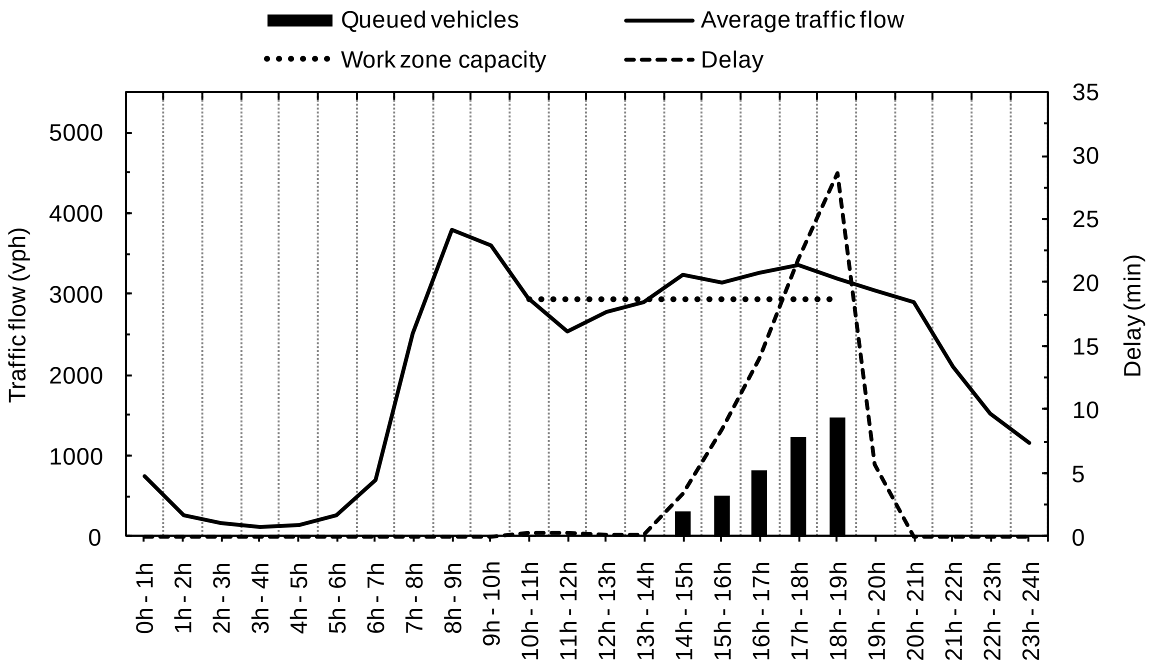

Figure 10 – Number of queued vehicles and average hourly delay for alternative 4

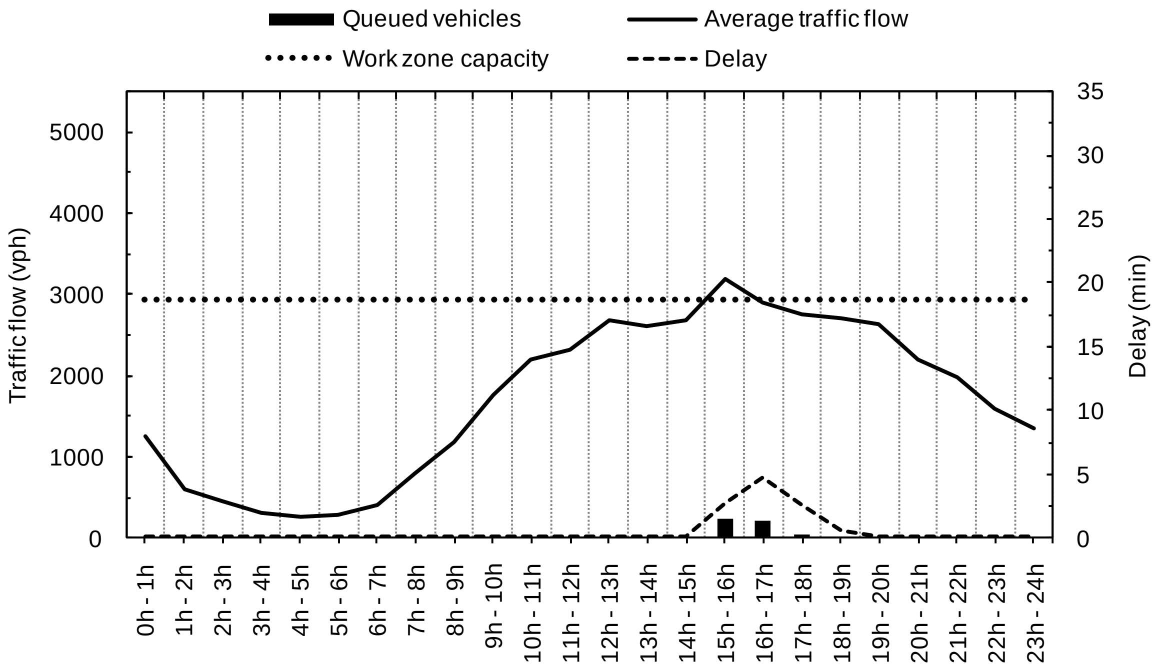

Figure 11 – Number of queued vehicles and average hourly delay for alternative 5

It also should be noted that in alternatives 3 and 5 (where layout B is used) the opposite direction traffic flow will also be affected.

It is not within the scope of this paper to fully analyse the results obtained since it is mainly focused on the model framework discussion. However, some of the results obtained merit discussion here. In what concerns to intervention cost, alternative 4 is the one with a lower cost, due the fact that all the intervention occurs in weekday period (with lower labour cost). Alternatives 3 and 5, where there is the need of consecutive work shifts are the ones with higher costs. However, these are the ones with a much lower duration in terms of working days. Alternative 1, since all the work occurs during night-time, is the one with less impact on users (in terms of delay) but 14 consecutive working days are needed to complete the intervention. Obviously, if it is desired a lower duration, alternative 3 and 5 are feasible options. Finally, it should be noted that alternatives 4 and 5 are only suitable for traffic distribution II.

CONCLUSIONS

This paper has focused on a new assessment methodology of pavement preservation investments by comparing systematically different attributes, describing them in terms of layout, inputs, variables and outputs. The successful model validation through the comparison of estimated attributes with other methodologies' results and, its calibration using different kinds of maintenance interventions, are a crucial step. Then, each pavement preservation intervention can be evaluated in such a way that the decision-maker may obtain a set of feasible and established alternatives. Subsequently, the use of multiple criteria decision-making analysis emerges as a more suitable tool to address the decision-maker's different preferences as well as different site and project needs.

Moreover, important analyses could be made with this method, such as the comparison of weekday versus night-time or weekend working; or the evaluation of the trade-off between shorter interventions with higher user delays and longer interventions with smaller user delays. In terms of the differences identified in the computed attributes of the several alternatives that can be chosen for a single intervention, the importance of this kind of analysis was demonstrated, working as a valid aid to engineering judgement normally involved in this type of decision-making.

A main drawback of the proposed method, at this stage, could be that the network effect is not considered. The influence of drivers that choose another road to avoid queues at roadworks or even the drivers that choose to travel on the same road at different times in order to avoid delays remains ignored by the model. It also does not evaluate important issues related to night-time work (e.g., noise and the greater need for construction joints, affecting pavement roughness). Given the variation in many of the model inputs, the move to probabilistic analysis is also expected.

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