# Pavement Management System model using a LCCA-microsimulation integrated approach

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**Abstract**

The maintenance and the rehabilitation of the urban road pavements are not often based on systematic program and scheduling but rather on emergency or on other not identified reasons.
Moreover the Life Cycle Cost Analysis (LCCA), the only peculiar procedure for the management pavement, finds its own application for highway and motorway, even if it is possible to search the best investment for the urban interstate and arterials.
By the light of the quantity of the involved resources, it seems necessary to define an operative methodology for programming the maintenance and rehabilitation activities for the urban pavement. The paper is oriented towards the development of a multidisciplinary approach to make decision on management of urban pavement using the basic concepts of the LCCA and micro-simulation model to define a scheme of work zone that minimizes the delay on the traffic flow.
The best rehabilitation strategy should be characterized by the lowest users' cost that depends on the time period of the work zone, which is conditioned by both own scheme and the provided treatment, and on "social cost" as increased travel time for queue generation .
Different scenarios for different work zone plans were developed and a micro-simulation model was used to assess increased total travel time of a traffic flow within the maintenance area.
In this work an analysis by means of the above mentioned approach was carried out on real scenario in the city of Palermo in order to point out the several frames of the adopted methodology.

*Keywords – road pavements, life cycle cost analysis, micro-simulation, work-zone*

## 1. Introduction

The municipal management of road pavement makes use of decision making tools being able to establish the priorities and to identify the most suitable maintenance and rehabilitation activities under the budget constraint.

In densely populated areas, the need is mainly to limit the increasing cost not only in terms of activities cost but also in terms of users' one.

Therefore the maintenance and rehabilitation plan have to be analysed as a real economical investment in order to select the most effective strategy not over short term but over consistent time period equal to five years at least.

The well-known analytical method is the Life Cycle Cost Analysis (LCCA) that allows to evaluate the several costs of different investment alternatives over an established time period (i.e. analysis period).

Such method is largely utilized for highway and motorway pavements which require much more resources, in terms of construction and rehabilitation costs, than municipal road ones.

Among the different costs that must be analysed and assessed the user costs are an aggregation of three separate cost components: vehicle operating costs (VOC), user delay costs, and crash costs.

In urban area the LCCA application has to properly take in account the increased user costs due to the work-zone that gives rise to variations in the users' behaviour in terms of route, time travel, period and vehicle utilisation.

These variations are more complex to be expected and assessed than the ones on highways and motorways for which the range of alternatives is usually not much wide.

The effects of the work-zone on the urban traffic flow and so on the user costs can be properly evaluated by means of the micro-simulation tools being able to estimate traffic within the involved area.

Therefore an integrated methodology with a framework based on LCCA principles and micro-simulation models could be the most suitable tool to select the best pavement maintenance or rehabilitation strategy which minimize the total cost consisting of the technical activities costs and of user costs.

In order to search the best investment for urban pavement two issues have to be deeply investigated: the maintenance or rehabilitation treatment because the scheme and the duration of the work-zone strongly depend on such treatment; the value of the users' cost and its percentage of the total cost of each several alternative.

## 2. Basic principles of LCCA

All rehabilitation and maintenance projects should consist of some level of economic evaluation in order to determine the most cost effective method and timing. The FHWA report FHWA-SA-98-079, Life-Cycle Cost Analysis in Pavement Design defines life-cycle cost analysis (LCCA) as: "…an analysis technique that builds on the well-founded principles of economic analysis to evaluate the over-all-long-term economic efficiency between competing alternative investment options. It does not address equity issues. It incorporates initial and discounted future agency, user, and other relevant costs over the life of alternative investments. It attempts to identify the best value (the lowest long-term cost that satisfies the performance objective being sought) for investment expenditures."

It is relevant to notice as the sensitivity of the LCCA outcomes depends on several parameters. As input parameters are changed, the cost-effectiveness of alternatives will change and so the hierarchy of alternatives could vary.

Typically, LCCA involves the following steps: initial strategy and analysis decisions, costs estimate, alternatives comparison, results analysis and in case alternatives re-evaluation.

### *2.1. Initial strategy and analysis decisions*

Certain baseline decisions, estimates and assumptions are needed in order to establish the parameters under which a LCCA can be carried out. In particular the alternative pavement design strategies is needed in order to evaluate two or more different pavement design strategies and determine their relative value. A "pavement design strategy" can be categorized as the combination of initial pavement design and necessary supporting maintenance and rehabilitation activities.

The best forecast of these latter activities (e.g. when maintenance and rehabilitation activities should be scheduled) depends on the reliable expectation of pavement performances over time.

On the basis of these assumption an appropriate analysis period can be chosen and appropriate cost estimates made.

The analysis period is the measured time in years as regards which different alternatives have to be evaluated in terms of total cost. Generally the analysis period of rural pavement strategies are longer than urban ones (30 versus 10 years in average).

### *2.2. Costs estimate*

The estimate has to take in account of the agency costs and users ones for each alternatives.

The first ones are all costs incurred by the owning agency over the life of the project. Obviously items common to all alternatives have not to be taken in account because each alternative is compared to each other.

Agency costs include: preliminary engineering costs and contract administration cost associated with engineering design and contract administration respectively; initial construction and construction supervision costs associated with each alternative; maintenance and rehabilitation costs.

Ultimately it needs to calculate the salvage value of an investment alternative at the end of the analysis period. This value can be zero or more than zero (i.e. an agency benefit) and consists of two major components: the net value from recycling the pavement (residual value); the remaining life in a pavement alternative (residual serviceable life) that can be estimated in proportion to the cost of the last rehabilitation activity.

The user costs are all costs incurred by the user of the facility during the construction, maintenance and/or rehabilitation and everyday use of a roadway section.

The amount of the users costs can be several orders of magnitude larger than agency costs and so its estimate is absolutely needed to correctly analyse the different alternatives and to make a decision.

User costs can be divided into two categories: costs associated to normal operation when the road facility is free of construction, maintenance, and/or rehabilitation activities that restrict the capacity of the facility. These costs usually depend on pavement roughness.

The other category is the associated cost to the work zone that occurs when the capacity of the facility is restricted and the traffic flows are disrupted.

Generally only work zone user costs are evaluated because the normal operation user costs can be considered equal for all alternatives. The user costs are an aggregation of three separate cost components: vehicle operating costs (VOC), user delay costs, and crash costs. The first component includes all costs associated with operating a vehicle including fuel, oil, part replacement, upkeep and maintenance; the second component includes the costs associated with road users' time; the third includes the costs associated with road accidents.

### *2.3. Alternative comparison*

The comparison of several alternatives over the analysis period is carried out using Net Present Value (NPV).

NPV is determined by discounting all project costs to the base, or present, year. Alternatives are compared according to these base year costs. As the benefits of keeping the roadway above an established terminal serviceability level are the same for all alternatives, the NPV can be expressed by the following equation:

$$NPV = initial\,cost + \sum_{j=1}^{N} rehab\,cost_j \left[ \frac{1}{(1+i)^{n_j}} \right] \qquad (1)$$

where:
$i$ = discount rate,
$n$ = year of expenditure.

The lowest NPV identifies the best alternative at this step.

### *2.4. Results analysis*

Once NPV's have been calculated for all alternatives, a sensitivity analysis of several strategic or major inputs should be carried out. The variability of these parameter within a reasonable range and the assumption of one value rather than another might cause variation among the NPVs of alternatives and thus on overall LCCA.

A different analysis approach (probabilistic analysis also called risk analysis) might be carried out once the probability distribution of the major inputs has been available.

But this kind of approach is based on complex and reliable data that are not always available; its cost might not be justified in terms of time and resources.

## 3. Traffic micro-simulation model

The micro-simulation has been applied with growing frequency over the past decade or more in the field of transportation system analysis [2]. The required analytical tools to support management strategies or travel demand need to provide a detailed assessment of how traffic operates and travellers respond to system impacts. In micro-simulation models, traffic flow is represented by individual vehicles with their own attributes (e.g. speed, acceleration/braking rate, etc.) that interact with other vehicles on road link on which they are traveling. Many simulation models were implemented in software packages allowing the analysis of the traffic flow over a road network.

Such models, based on driver behaviour concepts, are also able to simulate the traffic flow in presence of any disruption such as work-zone and accident. They require detailed geometric features, demand data and a large number of calibrated parameters to accurately model driver behaviour in the network. Since microscopic simulation models require significantly more data and analysis resources than macroscopic models, the first models provide broader data set than the second involving a large number of outputs. The choice and number of them depends not only on the type of problem being analyzed, but also by the project scope and objective.

For example, in most applications in particular speed, acceleration, route, time headway are investigated [11].

Generally the vehicle parameters are needed; for vehicle *j* (size-*j*, delay To Start-*i*, safe Distance-*i*, vel max-*j*,) [9], where:

- size *j* is the length of the vehicle *j*.
- delay To Start-*i*, is the delay to start after a total stop occurred.
- safe Distance-*i*, is the preferred safe distance between vehicles.
- vel max-*j*, is the preferred maximum velocity of vehicle *j*.

Within every scenario increased travel cost can be coupled with change in driver's decision due to the disruption. In presence of work-zone, the increased travel cost depends on several factor such as the extent of work-zone itself, the duration of activities and the type of treatments. Thus, through the simulation model, the optimal solution, in terms of the lowest user's cost, can be identified by selecting the more suitable work-zone scheme among the designed ones.

Technically and economically speaking, the main advantage arising from the micro-simulation model consists of getting output data by surveying the scenario 0 (in absence of cause of disruption). So a well designed survey about the involved area and traffic is needed.

## 4. Objectives

In urban context the pavement management system is often implemented by allocating resources over the road network on the basis of the emergency rather than in accordance with established plan and program.

On the other hand as very often the municipal budget for rehabilitation activities is very scant and thus plan and program could fail to apply.

Moreover from the point of view of citizen in presence of work-zone the social, environmental and user costs grow up by increasing of noise, pollution, accessibility reduction, travel time.

Therefore the municipal management must have well-founded operating procedure as much effective as the resources are scant and the economical and environmental impacts are heavy.

The work was aimed at developing a LCCA micro-simulation integrated methodology being able to select the most suitable pavement rehabilitation strategy which minimize the total cost consisting of the technical activities costs and of user costs. Such integrated methodology seems to be needed since the systematic LCCA application is mostly oriented towards big projects (rehabilitation of motorway and highway pavement) in rural areas where the work zone causes enough foreseeable variation of traffic flow in terms of delay, speed, queue, density over involved road network. [6, 7, 10, 12]. Instead, in urban areas the variation of traffic flow is usually more complex to foresee and to analyze because the traffic distribution over the road network depends on many parameters which substantially generate a random process depending on time.

The micro-simulation model is the powerful tool able to describe the users' behaviour in presence of work zone once some traffic data have been recorded within the involved area free of rehabilitation activities.

## 5. Methodology

Generally the principal aim of Pavement Management System is to establish the priority of the rehabilitation activities over the own road network by the light of pavement distresses.

Every strategy of rehabilitation should be developed and evaluated over a consistent time period equal to five years at least. Once the management has identified the type of treatment, scheduled the activities and evaluated their duration, it needs to assess the direct costs (i.e. technical activity costs) and indirect costs (i.e. user costs) in order to compare respectively the initial direct cost to the annual budget and the NPV of each possible alternative to the other ones.

Referring to user costs their amount strongly depends on both the duration of activity and the scheme of work-zone; on the other hand the chosen type of treatment and the layout of the road influences the duration of activity and the work-zone. In other words the work-zone scheme needs to be designed according to technical and economical requirements of both agency and user.

The approach to the selection of the best rehabilitation strategy consists of several steps: pavement distresses analysis, treatment and work zone design, intervention strategies (alternatives), micro-simulation model, overall cost evaluation and comparison of alternatives.

### *5.1. Pavement distresses analysis*

The pavement distresses analysis could be carried out using both friction, roughness and bearing capacity equipment as SCRIM, SUMMS, ARAN, FWD, GPR and image analysis.

In urban areas the use of these equipments is not suitable because such survey involves a big quantity of economical resources and, above all, implies the entire or partial closure of the street to the traffic. In this case, if the dimensions on the road layout are not too large, the pavement distresses analysis can be carried out by means of a photographic survey of distresses.

On the basis of the catalogue containing [5] several category (Table 1), and type of distress (Figure 1) the analysis can be implemented by identifying frequency and gravity, according to three levels of severity, of each distress. The analysis has to be supported by a photographic file of all existing distresses over the pavement.

Together with the above mentioned distress, other kind of minor defects, such as reduced difference level between pavement and sidewalk and increased difference level between pavement and drain, can be not rarely found. These defects can generate high risk for users since the drainage gets compromised during heavy rainfall.

*5.2. Treatment and work-zone design*

The treatments depend on both the likely cause of distress and the available economical resources. Thus, it is needed to distinguish the typical treatments of maintenance from the rehabilitation's options (Table 2). These latter imply major agency's costs, longer duration and wider area of the work-zone than maintenance's options.

On the other hand the effectiveness of rehabilitation is usually greater than maintenance's one because, for reaching the same performance of the pavement over the time, the rehabilitation's option is less recurring than maintenance's one. Having said this the user's cost should be reduced over the time and the investment strategy could turn out to be excellent in terms of NPV.

The scheme of the work-zone is strictly linked to the chosen strategy but it also strongly depends on the hierarchical role of the involved street within the urban network.

Some work-zone schemes can be summarized in Table 3.

Tab. 1 - Distresses categories and types

| SURFACE TEXTURE DEFICIENCIES | DETERIORATION | DEFORMATION | PATCHING | STRUCTURAL DISTRESSES |
|---|---|---|---|---|
| Polishing | Ravelling | Overlay Bumps | Patch | Transverse Cracking |
| Bleeding | Stripping | Rutting | | Longitudinal Cracking |
| | Pumping | Hollows | | Alligator Cracking |
| | Cracking from Compaction | Shoving | | Deep Potholes |
| | Block Cracking | Depression | | Collapse |
| | Surface Potholes | | | |
| | Wearing course detachment | | | |

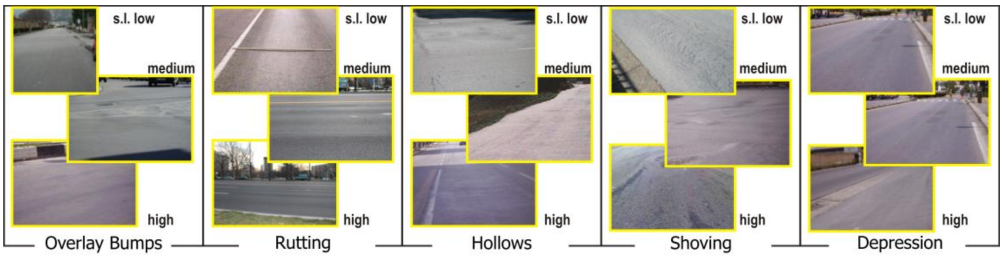


Fig. 1 - Example of distress overview

Tab. 2 - Maintenance and rehabilitation solutions

| MAINTENANCE SOLUTIONS | REHABILITATION SOLUTIONS |
|---|---|
| Potholes Filling | Surface Enrichment |
| Patching | Slurry Sealing |
| Restoration of Asphalt Surface Without New Asphalt | Splittmastix Asphalt |
| Crack Filling And Sealing | Resheeting |
| | Resurfacing |
| | Reconstruction |
| | Full-Depth Repair |

Tab. 3 - Work-zone scheme for bidirectional two-lane street

| TRAFFIC OVER WORK-ZONE | TYPE OF THE WORK-ZONE (SCHEME NUMBER) |
|---|---|
| No | Over entire roadway (1 Scheme) |
| Only whole lane | Turnover on single-lane (2 Schemes) |
| Whole lane and partial opposite lane | Turnover on partial single-lane (4 Schemes) |

### *5.3. Intervention strategies (alternatives)*

The relevant intervention strategies are based on a program of scheduled rehabilitation and maintenance solutions, even if the maintenance activities' cost could be considered common to every strategy. Several alternative should start from a full-depth repair (initial intervention) for pavement showing recurring and severe distress as rutting and cracking; instead, in less heavy conditions, the resurfacing option could be a suitable solution. The technical decision making on strategy is deeply influenced by two peculiar parameters: the analysis period and the expected life of designed pavement. The first represents the temporal horizon over which the NPV of the strategy has to be calculated. Of course the analysis period must be the same for each strategy because the analysis may be consistent with the objectives. The expected life represents the pavement service life in years of the initial intervention of given alternative. Once the strategies have been established, the duration of each single intervention has to be calculated in order to estimate the permanence time of the work-zone (Figure 2). However several strategies should be implemented during a propitious period such as summer time for reaching two specific goals: best climate conditions for treatments (i.e. high ambient temperature for laying and compaction); reduced disturbance between work-zone and users because of likely lowest traffic flow over year.

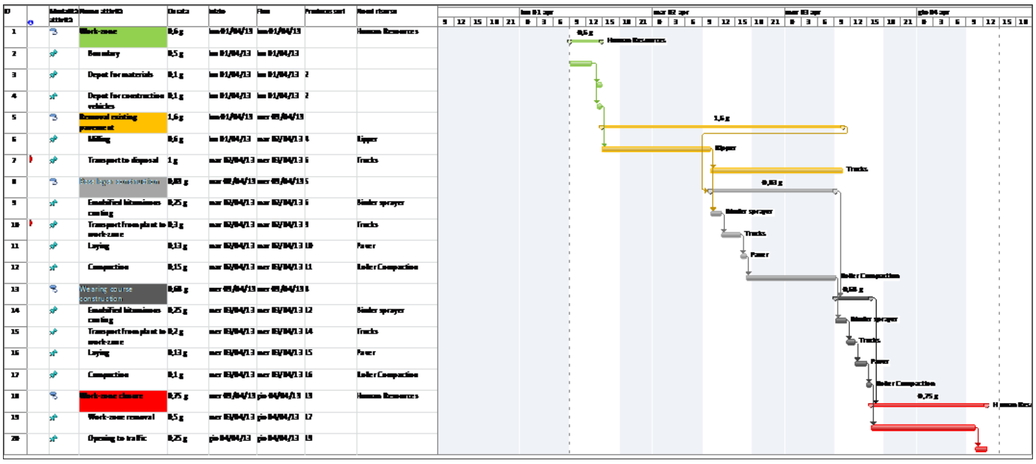

Fig. 2 - Gantt chart of resurfacing activities

### *5.4. Micro-simulation model*

The adopted model is based on Wiedemann's theory about psychophysical perception. This approach provides for some algorithms modeling representative parameters of driver behavior: car following, lane change and gap acceptance. The model operates on a population of driver database that depict the state, characteristics, and behavior of each unit in the database. Methodologies for calibrating traffic microsimulation model have been proposed in many recent publications [1, 3, 4, 8]. Some of the existing methodologies are based on the estimation of mean values rather than measures of variability. Similarly to some existing calibration methodologies, our experimental calibration tested and fit between simulated output and observed measurements. The behavioral input for the microsimulation can be determined by means of video recorded completed O/D survey.

Each simulation should be repeated 8 times at least to provide confidence level equal to 95%.

The performance of the system can be tested by means of measure such as average trip duration and average queuing time. Dynamic Simulation of Income Model (DYNASIM), developed and maintained at The Urban Institute, was used.

Traffic is distributed to hours in the weekday day using survey profile. These hourly directional flows are the required format of traffic data for input into DYNASIM.

Running DYNASIM to simulate traffic movements on a road includes the following:

(1) Create a background map (using AutoCAD drawings) and scale it;
(2) Draw the links on top of, and in line with, the road alignment;
(3) Assign the lane number and traffic data to those links;
(4) Generate the links for traffic in the opposite direction;
(5) Repeat (3) for the links in the opposite direction;
(6) Run the simulation.

The procedure contemplates three simulations for each hourly period under certain hypothesis: permanent or variable traffic demand depending on the work-zone scheme; queue running out within an hour; the speed limit being set to 20 Km/h within work-zone area.

The performance of the system can be tested by means of measure such as average trip duration, average queuing time and average crossing queue time.

### *5.5. Overall cost evaluation and comparison of alternatives*

The overall cost of a given strategy is the sum of agency's cost and user's cost. According to the first addend only the cost of construction and treatments should be taken into account because the others, such as engineering and administration cost are common to all alternatives.

As regards the user's cost, the proposed method takes into account only three components as against the seven ones provided by LCCA: the delay cost due to changing route and to crossing queue, the delay cost and vehicle operating cost due to queuing.

Unlike LCCA for highway and motorway pavement, the other cost, such as delay cost and vehicle operating cost due to speed variation, are not considered because the analysis is focused on interrupted flow condition. In accordance with LCCA the user's cost value are summarized in Table 4, where the delay cost are combined [13].

The reliability of the comparison of the alternatives strongly depends on the discount rate *i*. In this work we used real discount rate reflecting the true time value of money with no inflation premium. Such parameter should be estimated by evaluating historical trends of one conservative indicator of the opportunity cost of money, over consistent time period with the time of the investment. Finally the discount rate can be considered equal to average value over the time in years.

Tab. 4 - Components of user's costs

| TYPE OF VEHICLE | DELAY COST [€2013 vehic/h] | VOC [€2013/1000 vehic • h] |
|---|---|---|
| Passenger Car | 13,53 | 809,32 |
| Motorcycle | 6,76 | 405,07 |
| Bus | 21,66 | 897,41 |
| Heavy Vehicle < 3,5 t | 17,60 | 853,36 |
| Heavy Vehicle > 3,5 t | 21,66 | 897,41 |

## 6. Case Study

The LCCA micro-simulation approach has been applied in order to select the optimal strategy for road pavement in the urban area of Palermo, in particular along Corso Pisani that is a 440-m-long section. The road pavement showed bad conditions above all in terms of roughness and bearing capacity. Some results of the distresses survey are reported in Figure 3.

The designed work-zone (scenario) are two: the first for traffic over only whole lane and turnover on single-lane that implies two schemes; the second for traffic over whole lane and partial opposite lane and turnover on partial single-lane (four schemes). In Figures 4-5 two schemes of the different scenarios are reported. Two basic alternatives are considered and founded on 8-years and a 12-years pavement service life. The strategies (Tables 5-6) have been studied to reach 15-years analysis period according to observed distresses. The salvage value of the both strategies has been considered equal to zero. Thus four investment alternatives were examined. Even though micro-simulation models are definitely desirable, they require details about transportation facilities and observed travel behaviour at a granularity that is not typically available to urban planning agencies. Therefore, for each arc of the network the study was focused on size (length and width), type, number and position of the parking, run directions (the traffic rules, no parking zones).

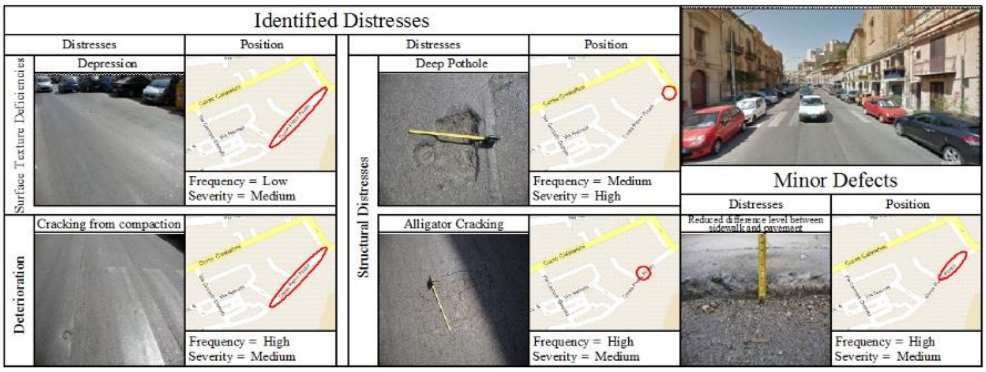


Fig. 3 - Photografic survey

Fig. 4 - Work-zone on whole lane

Fig. 5 - Work-zone on partial lane

Tab. 5 - Treatments on designed pavement (initial intervention) with 8-years service life

| STRATEGY PLAN *(pavement service life 8 years)* | | |
|---|---|---|
| **Year** | **Treatments [(R) = Rehabilitation; (M) = Maintenance]** | **Duration [Hours]** |
| 2013 | Full-depth repair (R) | 16 |
| 2016 | Crack filling and sealing (M) | 2 |
| 2018 | Restoration of asphalt surface without new asphalt (M) + Crack filling and sealing (M) + Pothole repair/Patching (M) | 5 |
| 2021 | Reconstruction (R) | 12 |
| 2024 | Crack filling and sealing (M) | 2 |
| 2026 | Restoration of asphalt surface without new asphalt (M) + Crack filling and sealing (M) + Pothole repair/Patching (M) | 5 |

Tab. 6 - Treatments on designed pavement (initial intervention) with 12-years service life

| STRATEGY PLAN *(pavement service life 12 years)* | | |
|---|---|---|
| **Year** | **Treatments [(R) = Rehabilitation; (M) = Maintenance]** | **Duration [Hours]** |
| 2013 | Full-depth repair (R) | 16 |
| 2018 | Restoration of asphalt surface without new asphalt (M) + Crack filling and sealing (M) | 4 |
| 2020 | Crack filling and sealing (M) + Pothole repair/Patching (M) | 3 |
| 2023 | SplittMastix Asphalt – SMA (R) + Crack filling and sealing (M) | 8 |
| 2026 | Crack filling and sealing (M) | 2 |

Each link of simulated road network was set as urban road with the same speed limit. The traffic flow survey was carried out in weekdays for five hourly periods, 7.30-8.30 – 10.30-11.30 am and 1.30-2.30 – 5.30-6.30 – 8.00-9.00 pm, in summer 2012. By means of videos recorded during the survey individual driver behaviour (car following, lane change, gap acceptance at intersections, etc.) and traffic conditions were studied. Moreover specific input parameters, such as origin and destination, number and type of vehicles were collected.

The micro-simulation model has been implemented using the data from scenario 0 in absence of work-zone (Do Nothing alternative from which the future build alternatives are compared).

The calibration of the model reached a successful conclusion because the standard deviation was less than 10% between measured data (in terms of velocity and traffic flows) and output of the DYNASIM software. As regards the velocity the measured values are recorded using a passenger car equipped with GPS. Seven different scenarios were simulated and compared: the first two involve the construction of the work in two phases, closing one lane at a time on the entire trunk and diverting traffic flow of the lane on which maintenance is performed on an alternative route. The remaining scenarios provide for the closure of one lane at a time for half the length of work zone, using an alternating one-way through a traffic light. In this way you can keep the original routes. For the scenarios 1 and 2 have been envisaged a rerouting flows system toward the only alternative route, while for the remaining routes, the length of the work-zone is very short (4 days) has made the assumption of “non elastic” travel demand. For each network scenario, two sets of simulations were performed corresponding to peak hour and off-peak hour. This study performed multiple runs in order to eliminate randomness in the simulations. The measure of performance as daily total travel time was evaluated in term of sum of travel time of every itinerary in peak hour and off-peak one within workday. The time horizon was divided into 600 seconds time periods of equal length. For each strategy the overall costs were evaluated as shown in Figures 6-9, considering direct costs referring to treatments and indirect costs referring to road users. By having evaluated historical trends of Italy Governments Bonds the real discount rate was considered equal to 0,21.

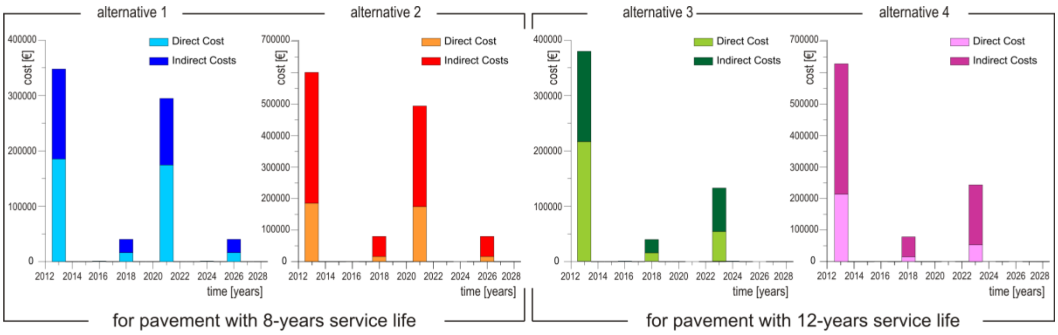


Fig. 6, 7, 8, 9 - Expenditure stream diagrams

This value derived by the average of the real discount rates over the last eight years (Figure 10). By comparing each alternative (Figure 11) some interesting considerations can be drawn:

- on equal terms of designed work-zone the pavement with highest service life shows the best economical performance at least under the examined strategy plans. In other words, by the light of very low value of the discount rate, the best alternative should involve huge expenditure for initial intervention and minor treatments along the time;
- on equal terms of designed pavement the work-zone providing for turnover closure of an entire lane seems to be the best option. In other words the traffic flow seems to be disrupted more by queue next to work-zone rather than by route alteration out of the work-zone;
- the designed work-zone greatly influences the performance of the investment because the user’s cost are higher than agency’s one (alternatives 2 and 4) or anyway comparable to each other (alternatives 1 and 3);
- the NPV difference in percentage between the best investment (alternative 3) and the worst one (alternative 2) is equal to 127%.

### 7. Summary, conclusion and future work

By the light of more and more growing demand of safety and high ride quality by road users and opposite reduced available resources for pavement maintenance and rehabilitation, a tool well-founded on systematic method, for effectively managing the urban road network, seems to be not postponed.

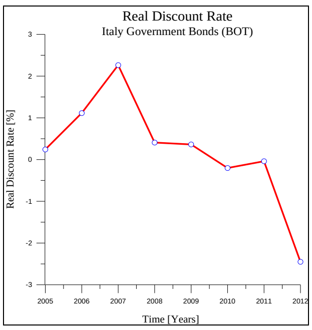


Fig. 10 - Historical trend

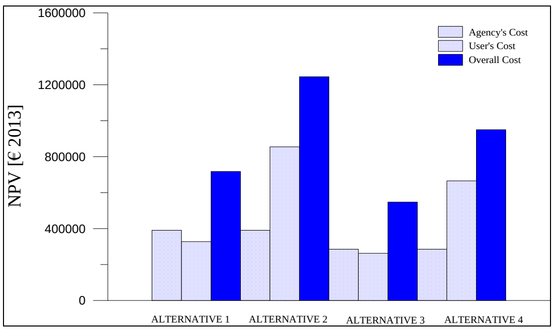


Fig. 11 - Overview of investment alternatives

This paper illustrated a new approach such as the integrated LCCA micro-simulation model to search the best investment among considered maintenance strategy plans of urban road pavement.

The proposed model was tested through a case study in Italian big town and the results gave rise to some outstanding considerations: in particular the notable influence of the work-zone on user's cost and so on the NPV of the investment.

Therefore the percentage of user's cost on overall cost could justify the effort of using the proposed model as a tool for improving decision making process about strategy plan for a given pavement segment.

The future work includes analyzing effects of road accident cost on overall cost even if available crash data are defective in urban areas, also because of quite lower gravity, mainly due to low speed, than other recorded over highway and motorway network.

Since the queue due to the work-zone determines the stop&go circulation. The future work will also take in account the increase of air pollution concentration as additional cost, in order to improve the estimation of total cost for interventation.

Finally we will simulate a punctual information provision in order to allow a smooth traffic flow outgoing as far as possible without network congestion. In this case, the micro-simulation model should be integrated with the DUE assignment technique. It reflects the importance of modelling the impact of simulation results on travel demand in the overall area.

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