Road User Interests as an Optimization Criterion for Austrian Motorway Maintenance

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ABSTRACT

Road infrastructure is not built and maintained for its own sake, but has to fulfil the needs and requirements of the users. In this respect the Austrian motorway agency determined road user interests as main criterion for the generation and evaluation of maintenance concepts.

In general concerning operating and maintaining road infrastructure, pavement management applications (PMS) focus on the material and structural parameters as well as the economic effects. Infrastructure maintenance concepts, just as the one currently used in Austria, mainly aim at the reduction of total costs for the agencies; still there are major costs for road users, third parties and environment, which have to be considered in order to refer to the total economic cost.

In the current Austrian pavement management system (VIAPMS_Austria) road users are primarily applied as weighting factor. One option of integrating road user costs is by including them into the optimization criterion (benefit/cost ratio). In the new approach the cost side should remain solely as agency cost (in order to guarantee the comparability of strategies), but the definition of the benefit has to cover all user aspects and include all user costs incurred. Concluded benefits could be summarized as total user cost savings over the whole analysis period for the chosen maintenance strategy.

The suggested changes have been applied on a representative part of the Austrian motorway network. The results have been astonishing; through changing the optimization criterion the proposed maintenance strategies change radically. Above all, there is a reduction in the duration of the construction work, which is accompanied by profound reduction of the treatments. As the benefits consist solely of user cost aspects consequently the condition of the road structure will be neglected. The methodology proposed offers the possibility to introduce boundary conditions for guaranteeing a good road condition.

This paper offers an optimized pavement management system which comprises agency and road user aspects. In the example application for a part of the Austrian motorway network user cost savings could be achieved through the proposed maintenance strategies, exceeding by far the inserted agency costs.

1 PAVEMENT MANAGEMENT IN AUSTRIA

The Austrian road network consists in total of approximately 120,000 km of roads. Highest traffic loads as well as high speed traffic are occurring on the 2,100 km of motorways. The primary focus of this research lies on this historically grown network with its variety of pavement constructions, pavement ages and conditions Due to those facts systematic operating and maintaining becomes more and more an issue.

The implementation of a modern pavement management system (VIAPMS_Austria) on the motorways has started about 15 years ago and is continuously enhanced. The main focus is still valid; it aims at an optimal performance and comprehensible assessment of all money invested. In the existing pavement management model road users are integrated as weighting factor using the AADT-value, but the cost and the benefits arising especially for users are not individually quantified and integrated.

Figure 1 gives an overview on both attempts, the grey outline represents the conventional pavement management system in Austria, which is primarily based on the road condition but also takes into account the traffic volume and the road inventory data. With this information the Total Condition Index (TCI) is calculated and developed for the whole analysis period. It merges the provided parameters on the one hand in respect of the condition of the structure (Structural Index) and on the other hand reflecting comfort and safety issues (Comfort & Safety Index). Based on the index deterioration all reasonable maintenance and rehabilitation strategies to secure a good road condition, the respective benefit (referred to as the change of the TCI due to treatment application) and the costs (agency costs) could be calculated (Weninger-Vycudil, 2003). Furthermore on the basis of the benefit-cost ratio and the budget available the optimal strategy for each segment could be chosen.

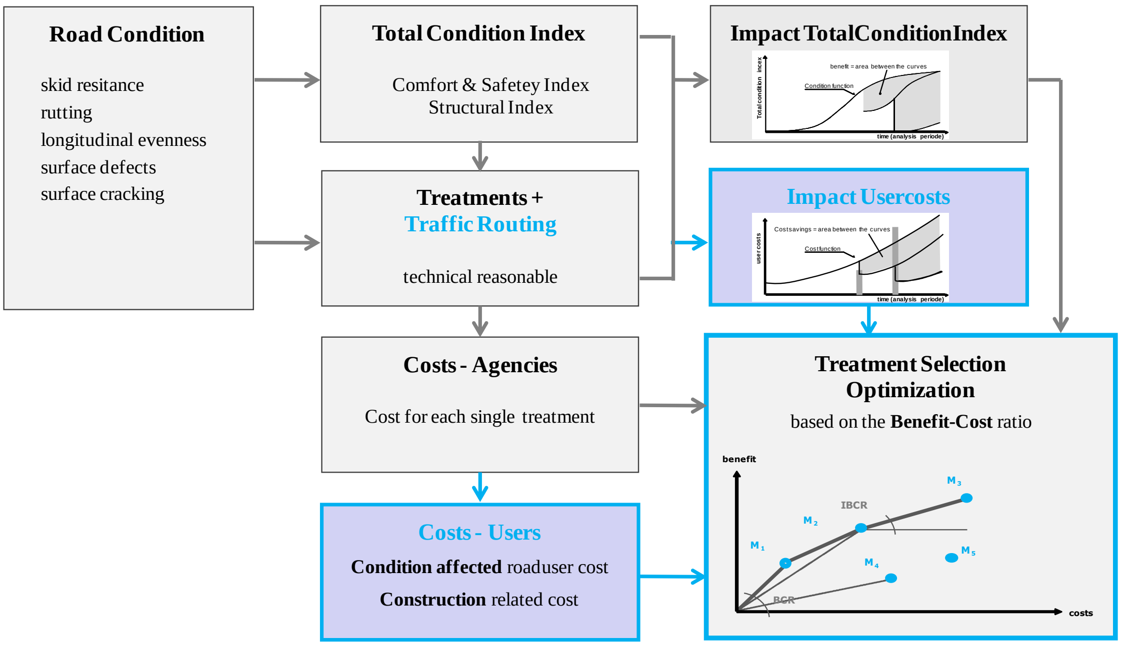


Figure 1: Flowchart of the Austrian Pavement Management System (conventional and user cost enhancement) (Brozek et al., 2009)

Figure 1 also includes the enhancement of including road user aspects into the Austrian PMS. The light blue parts represent the option of additional calculating road user costs (condition affected and construction related) and thereof quantifying a user-benefit as reduction of road user costs by applying a certain maintenance strategy (Brozek et al., 2009).

Finally this tool makes it possible to choose between agency optimized and road user optimized maintenance management strategies and always keeps an eye on the precondition of the restricted maintenance budgets.

2 ROAD USER COSTS

Internationally the question of road condition impact on users is of high importance and there are several projects dealing with this topic (e.g. Hermann et al., 2008 and FORMAT, 2006). From this pool of existing research the appropriate applications have been compiled and used as a basis for the developed application.

In order to integrate the occurring user cost they have to be made visible and listed with all corresponding aspects in terms of time-, accident and vehicle operating costs. Of similar importance are the interdependencies of road condition (directly linked to the effect on road users), type of maintenance strategies, traffic management as well as the duration of the construction work and road user costs.

Generally costs for road users may occur at two different time frames within a life cycle of a road or any other related asset. It can be distinguished between continuously occurring condition related costs and temporary construction related costs.

2.1 Condition Related Road User Costs

This aspect includes costs which are directly related to the road condition, so due to a deteriorating condition consequently the road user costs are raising. As shown in Table 1 these costs are summarized in three major categories: time costs, accident costs and vehicle operating costs.

Table 1: Compilation of impacts on condition affected road user costs

Category	Decisive factor	Relevant condition parameter
Time costs	Speed	Longitudinal evenness
		Water Film depth
Vehicle operating costs	Inclination	
	Speed	Longitudinal evenness
		Water Film depth
Accident costs	Additional accident rate	Skid resistance
		Rut depth

Depending on the condition of each section different cost groups have higher impact. For example a bad skid resistance leads to higher accident costs and a bad longitudinal evenness leads to higher time costs. Some examples of road user cost development dependant on the road condition deterioration are presented in the following figures. The calculations are valid for an AADT of 1000 vehicles (900 cars and 100 heavy vehicles). The individual cost for each road user is rather small, but as it has to be summarized over the whole life cycle period it gets more importance. Figure 2 presents the development of the time costs related to the IRI deterioration and Figure 3 shows the variation in vehicle operating costs for cars on highways and freeways. Figure 4 shows accident costs referring to the rut depth and skid resistance, as it could be calculated applying the findings from Schulze et al. (1975) and Kamplade (1988).This relationships used at the moment can easily be replaced by others as soon as more actual data is available.

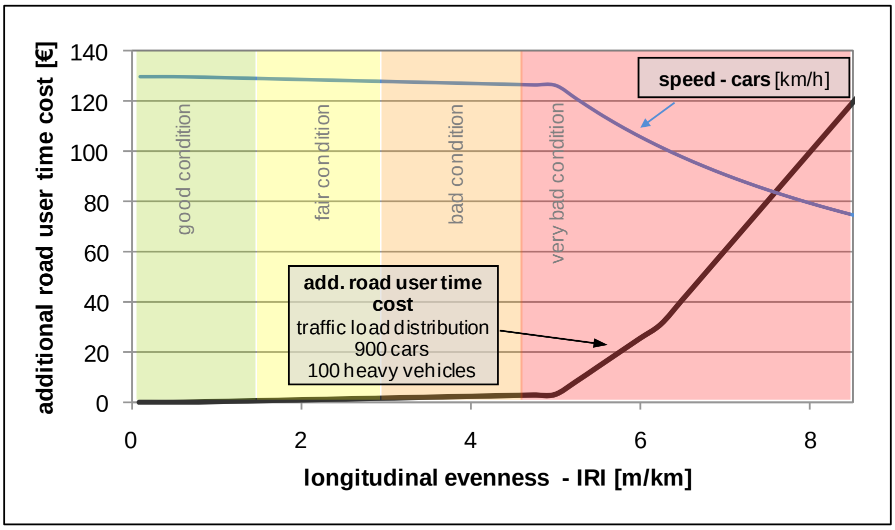


Figure 2: Development of additional Road User Time Cost (Brozek et al., 2009)

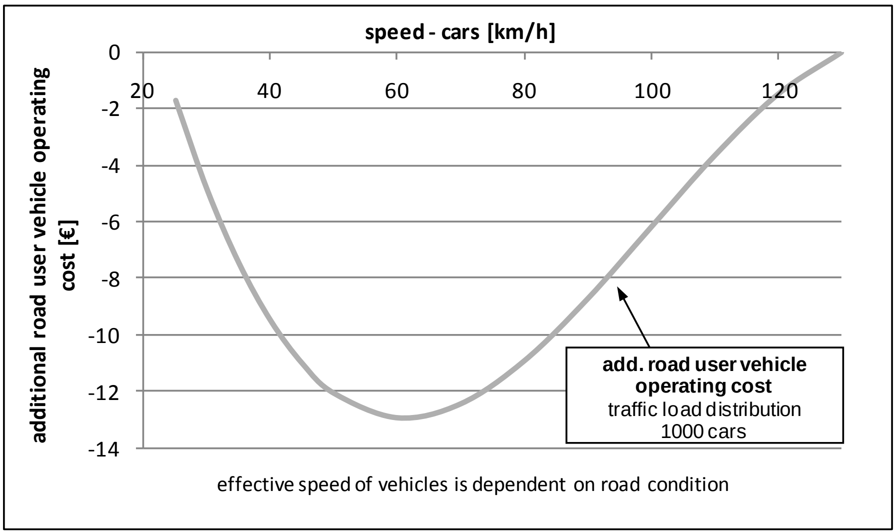


Figure 3: Development of additional Road User Vehicle Operating Cost (Brozek et al., 2009)

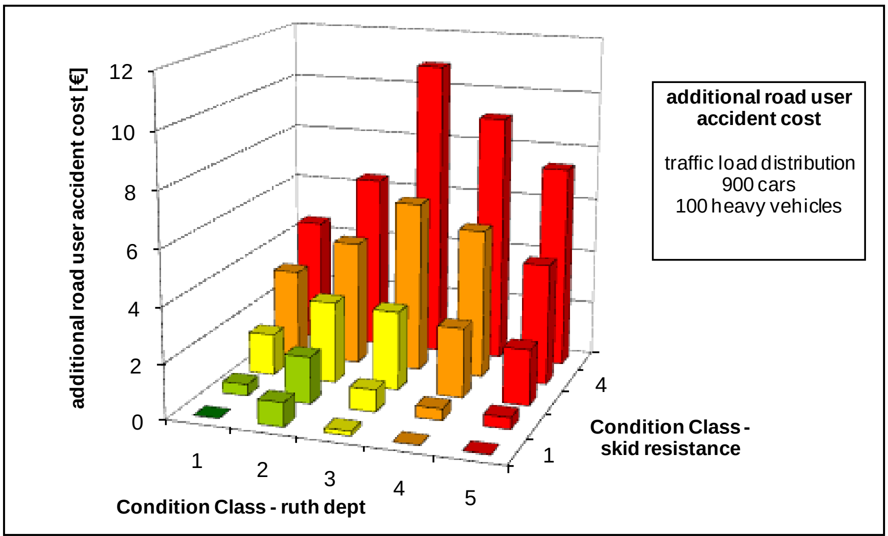


Figure 4: Development of additional Road User Accident Cost (Brozek et al., 2009)

2.2 Condition Related Road User Costs

Beside the road condition also the maintenance treatment itself has high impact on the road user. Especially in sections where the traffic load is close to the capacity limit. In those cases a treatment, which indicates a reduction in capacity causes delay and the formation of queues. This disturbance to road users can be directly calculated in terms of construction related additional time costs. They may also include the additional time which is needed for passing the construction area at a lower speed. This impact and the other relevant issues are listed in Table 2. It has be mentioned that construction related costs only occur during construction time, in years without treatment no construction related user costs are developed.

Table 2: Compilation of impacts on construction related road user costs

Category	Decisive factor	Relevant parameter
Vehicle operating costs	Speed	Construction site transit speed
Accident costs	Additional accident rate	Applied traffic routing
Time costs (construction site transit)	Speed	Construction site transit speed
Time costs (queuing)	Capacity	Applied traffic routing
	Traffic load	Traffic increase

Concluding from the list in Table 2 not only the type of maintenance treatment and therefore the duration of the disturbance has strong influence on the resulting construction related road user costs, but also the layout of the traffic management (responsible for the residual capacity which can be guaranteed) and the time (in strong relation to the occurring traffic amount) has a major influence. For the layout of the traffic routing during the maintenance phase a catalogue of frequently used and practical solutions has been developed to reduce the amount of variations without limiting the possibilities.

Those correlations have been tested and implemented in the existing Austrian Pavement Management System. Equations can be best visualised by their results, thus in the following chapters the resulting user costs as well as their consideration within the PMS are shown.

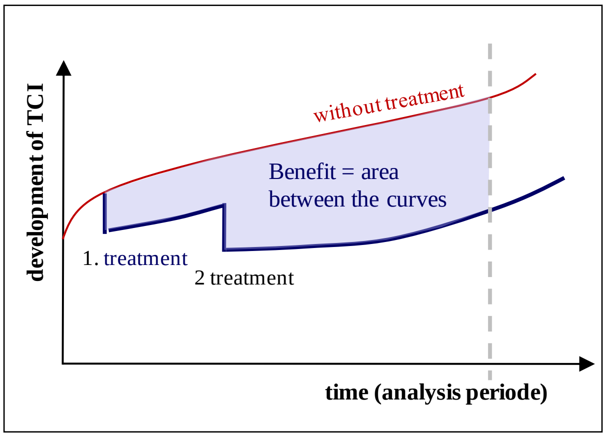
3 OPTIMIZATION PROCESS

3.1 Implementation of Road User Aspects in the PMS

More than the aim of calculating the total economic cost of all strategies for the analysed network was the advantage of directly comparing two different treatment strategies by its effect on the road user expressed as user cost savings. Furthermore this allows the integration of user interests in all relevant decisions (treatment selection as well as optimization process). As for each treatment the agency costs are calculated also a second cost figure is stored holding the economic user costs occurring with this treatment.

As conventional decision criterion the cost-benefit ratio of the agency cost and the benefit of the Total Condition Index (TCI, combining all individual condition parameters) is used. The benefit itself refers to the impact of a treatment on the TCI as the area between the curves (do-nothing and treatment curve of the TCI); see also Figure 5.

To guarantee comparability the same optimization method is used for the integration of user aspects. The user-benefit is generated by the reduction of user costs through implementing a treatment strategy, as before the “area between the curves” – method is used. The benefit itself is calculated in two steps, as illustrated in Figure 6. At first the benefit on condition affected road user costs due to the strategy (light blue area) over the whole analysis period has to be calculated. Secondly this value has to be diminished by the construction related road user costs (dark blue bar). All costs occurring are issued in terms of present (discounted) costs in order to enable the comparison.



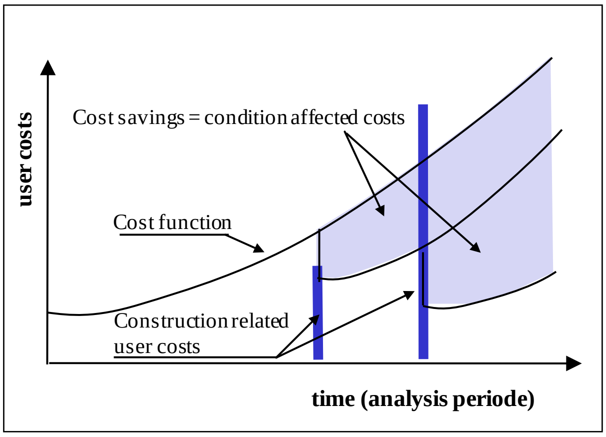


Figure 5: Benefit calculation (Weninger, 2003)

Figure 6: Total user costs of strategy (Brozek et al., 2009)

Depending on the desired level of aggregation the result can be shown for a single section or summarized for the whole network. In principle the result of the network composes of the individual sections (for some questions it is essential to consider the individual outcome).

3.2 Sample Network

The effect of considering road user aspects within the pavement management process can be best shown on a small sample network. The representative network consists of 1,250 km and equates in its properties (age, traffic, structure,…) and condition to the Austrian motorways and expressways. The network comprises sections with one up to four lanes and totals over 3,000 lane-km.

The condition distribution of the road pavement for the first carriageway is shown for the TCI and supplementary in form of the structural index and the comfort index. It can be noticed that for the TCI there are no sections in a very good condition, but on the other hand the very poor share is not too big either.

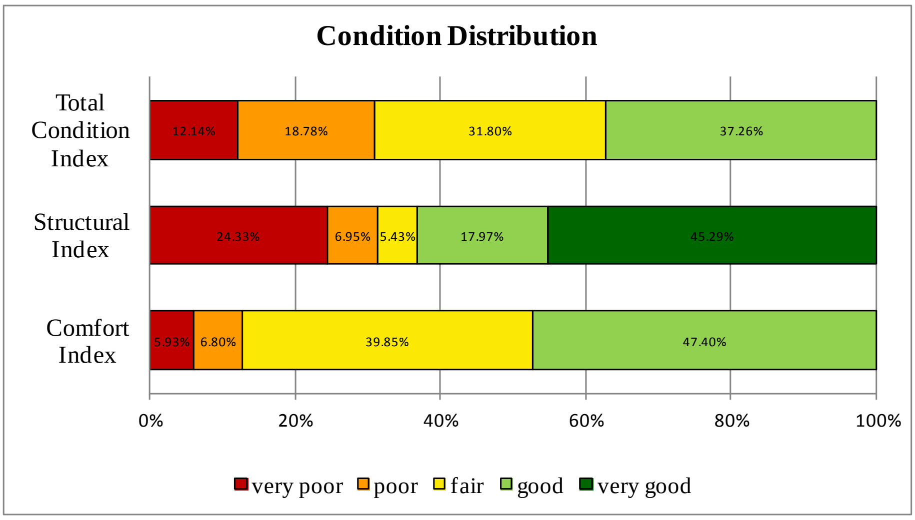


Figure 7: Condition distribution of sample network

3.3 Section Results

From the analysed network one single motorway section with a length of 5 km was chosen to show the detailed results in calculating user costs and integrating this value in the generation of the benefit-cost ratio.

The analysis is configured for a time period of 20 years and the analysed section has a moderate average section condition at the beginning of the analysis (TCI~3.5). Whereas the surface condition is slightly worse than the structural condition.

For the comparison of the optimisation criterion three different maintenance strategies are listed (for results see Table 3). The first option consists of a surface treatment in the third year of the analysis and later on a replacement of the whole structure (year 17). The second option also starts with the surface treatment in year three and continues only with a reinforcement of the asphalt layers in year 19 and the third option consists only of the surface treatment in year 3.

For all options the respective treatment costs (agency costs) are determined, they are furthermore the cost part of both optimization possibilities. On the benefit side conventionally the area under the curve of the total condition index (standard optimization) is calculated. The enhanced benefit criterion (total user benefit) consists of the condition affected user cost savings minus the construction related user costs.

Table 3: Sample section: listing of treatment costs and benefits for three maintenance options

	Option 1 **Surface (year 3)** **Replacement (year 17)**	**Option 2** **Surface (year 3)** **Reinforcement (year 19)**	**Option 3** **Surface** **(year 3)**
Cost criteria Costs of treatment (Agency costs)	3 740 260 €	1 468 770 €	523 923 €
Benefit criteria **Standard optimization (acc. figure 5)**: Total condition index	246 540	229 530	135 160
User cost optimization: Savings condition affected costs	11 557 894 €	11 552 439 €	11 475 398 €
Construction related costs	1 512 994 €	493 310 €	259 693 €
Total user benefits	10 044 900 €	11 059 129 €	filter to secure good structural condition

Comparing the three treatment options (with no budgetary restraints) the greatest impact on the structure itself could be achieved with the replacement (option 1) and this is consequently reflected with the highest benefit (referring to TCI). Taking user costs into consideration the ranking is immediately changing. Treatments with lower impact (reinforcement than replacement – option 2) still achieve higher user benefits. This is mainly caused by the shorter construction time which goes along with less interruption and lower construction related user costs. This is especially influencing the results for strategy three.

Nevertheless a good condition of the road substance has to be secured, otherwise at some point the construction might totally fail. Therefore a filter which sets a minimum value of 3.5

for the structural index has been implemented to ensure a given minimum condition and avoid only “cosmetic“ measures. This is what causes option 3 not to be part of the optimization.

Comparing the budget for treatment costs (agency costs) and the total user benefits which can be allocated with the invested money, the positive output of the treatment application is astonishing. In total (taking into account all network sections) the generated user benefit totals seven times the inserted agency costs.

3.4 Network Results

The main advantage of using an optimization tool for pavement management is in an automatic allocation of the available budgets on the sections with the biggest benefit. The corresponding output is usually shown in form of treatment distribution and the condition development information. Those graphs are also produced for the sample network, especially to compare the outcome of the conventional (standard optimization) and the user cost optimization The analysis was performed with no restriction on the budget. This enables the selection of the best alternative and causes in a larger spread of the results.

The changes in the treatment selection due the change of the benefit criterion (based on user cost savings) can be clearly seen in Figure 8. There is a strong shift from replacement-standard optimization to a not so strong rehabilitation-user cost optimization, especially in the second half of the analysis period. This is mainly caused by the shorter interference of the not so heavy treatments. Also the increased amount of surface treatments confirms this development. Not only the severity of the treatments shifted, but also the number of maintenance activities decreased in the user cost attempt.

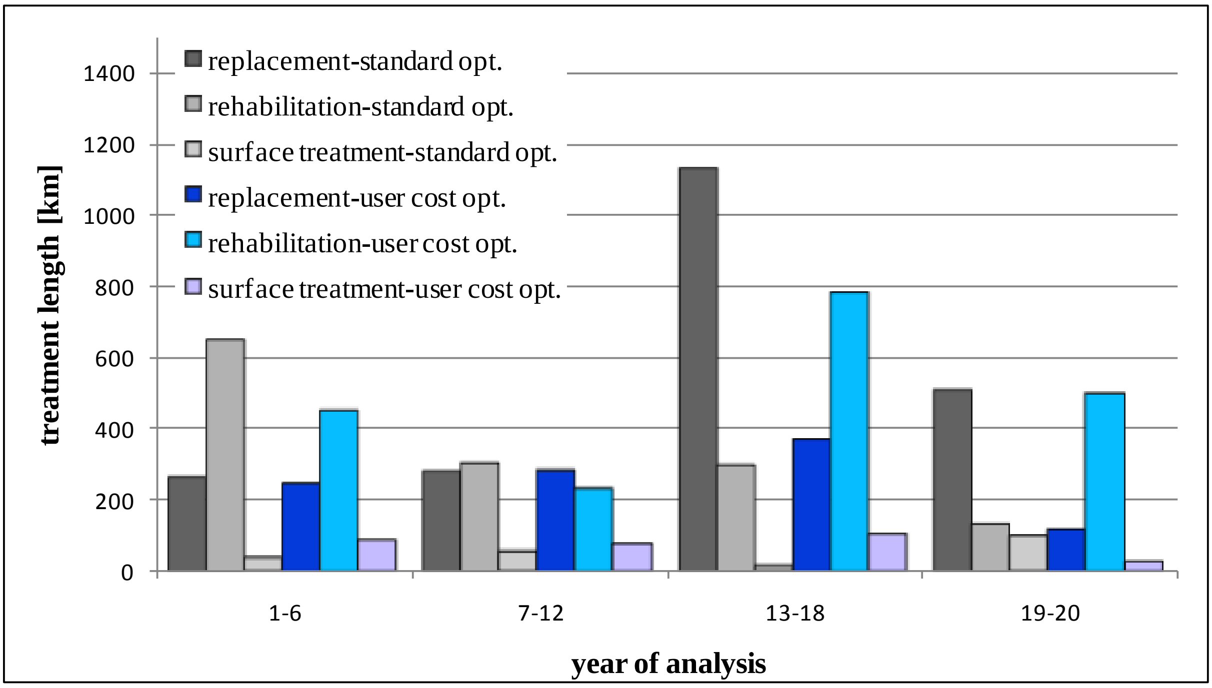


Figure 8: Comparison of treatment selection for the example network

Consequently, as the treatment selection changes and the total condition index is no longer used for the optimization criterion, changes in the condition distribution arise. Comparing Figure 9 and Figure 10 the increasing share of condition classes poor and very poor (especially in last four sequences, when no more treatments are set) is evident. On the other hand also the sections ranked “very good” are less.

To limit this increasing structural deterioration if one is looking at the user’s interests only (comfort and safety index) an additional requirement had to be implemented. With the restriction to not let the substance value fall below the warning level (3.5, between fair and bad) at the end of the analysis period, a well-balanced maintenance concept for road agencies and road users could be achieved.

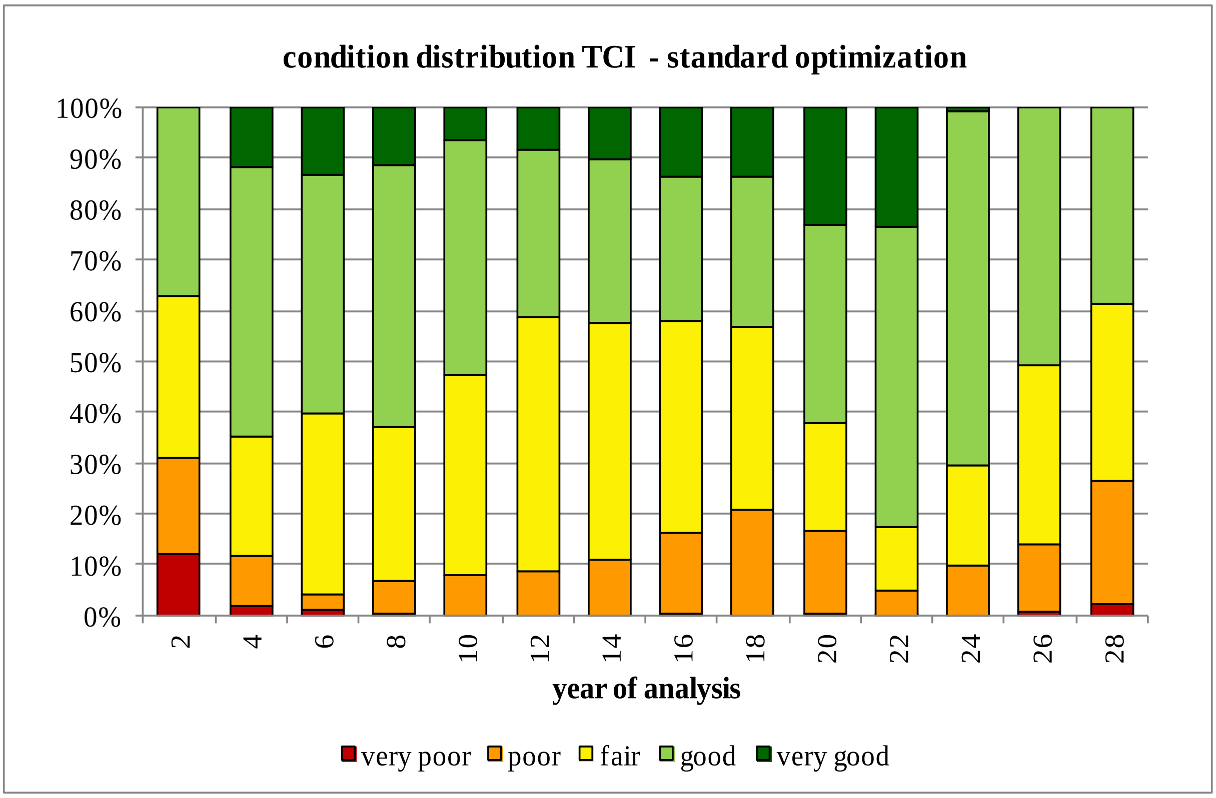


Figure 9: Condition distribution for TCI (based on conventional optimization)

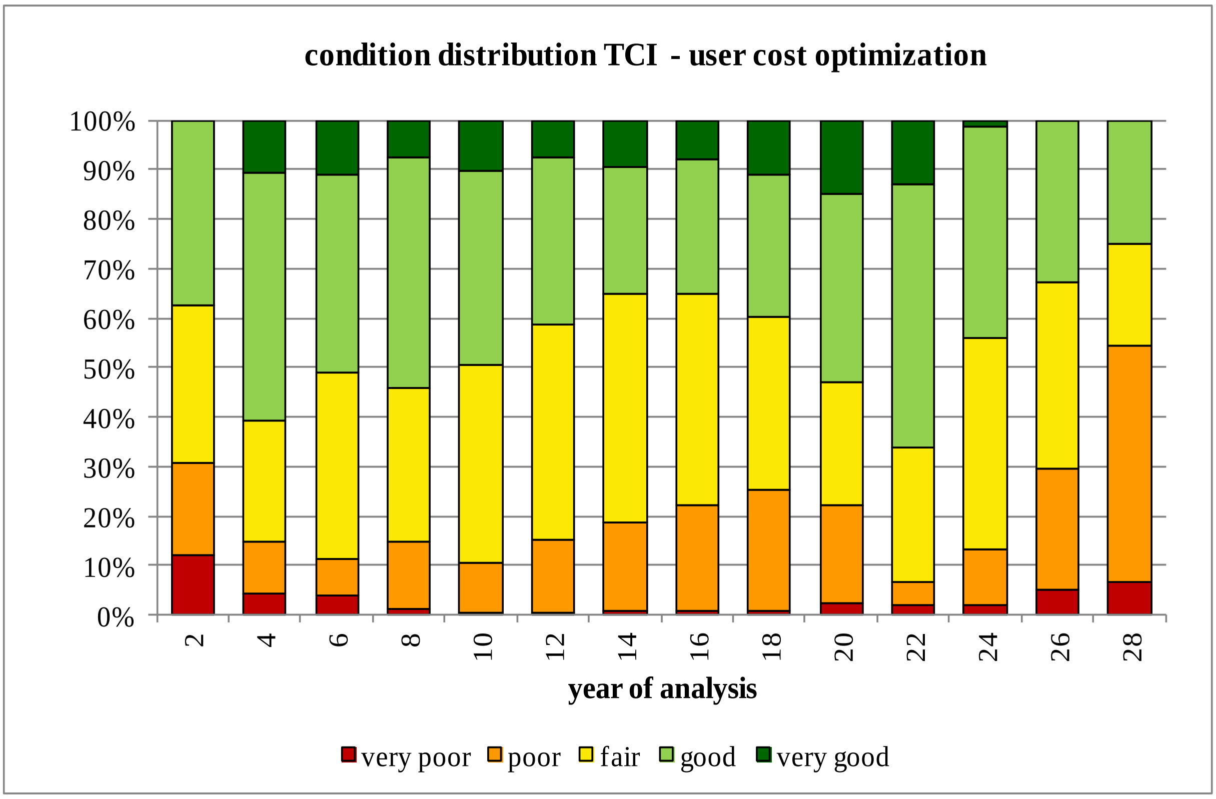


Figure 10: Condition distribution for TCI (based on user cost optimization)

4 CONCLUSION

With the presented tool it is possible to develop maintenance strategies and treatment lists and calculate the arising agency costs as well as the road user costs.

Taking road user aspects into consideration has a major effect on the maintenance strategies proposed within the pavement management system. This implementation leads to a minimum of disturbance and therefore to less replacement and more surface maintenance treatments. As shown the implemented algorithm covers two aspects: Firstly a good total condition of the road construction is secured (in addition to the user costs also a criterion to guarantee a good road condition has to be in place). Secondly the user cost savings are maximized (under the given financial boundary condition) and could be significantly raised in comparison to the current pavement management system. On the other hand it was necessary to secure a minimal structural condition of the pavement by implementing a limit for the structural index.

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