**DETERMINATION OF OPTIMAL WORKZONES IN A TRANSPORT NETWORK WITH A MIXED-INTEGER LINEAR PROGRAMMING MODEL**

**Charel Eicher**1**, Nam Lethanh**2**, Bryan T. Adey**3

1,2,3 *Institute of Construction and Infrastructure Management, Swiss Federal Institute of Technology (ETHZ), 8093, Zurich, Switzerland*;

e-mail:1 [eicherch@student.ethz.ch](mailto:eicherch@student.ethz.ch), 2 [lethanh@ibi.baug.ethz.ch](mailto:lethanh@ibi.baug.ethz.ch) and 3 [adey@ibi.baug.ethz.ch](mailto:adey@ibi.baug.ethz.ch)

**Abstract.** *One of the tasks of road managers is to determine the interventions to be included in work zones and the traffic configurations to be used during the execution of these interventions. This requires taking into consideration the costs related directly to the objects, such as the manual labour to execute the interventions, and the costs related to the use of the network, e.g. increased noise and increased accidents due to deviated traffic around the work zone that includes the interventions. It also requires balancing the increase in costs during, and the decrease in costs following, the execution of the interventions.*

*In this paper a mixed-integer linear model for determining optimal work zones on a road network is presented. In the model, each node represents an intervention on a road segment in the network, and each edge represents a change in the traffic configuration between two road segments. The model is illustrated by determining the optimal work zones (interventions and traffic configuration) on a road network consisting of 567 objects.*

**Keywords:** Highway interventions, intervention scheduling, workzone optimization.

# INTRODUCTION

One of the tasks of road managers is to determine the interventions to be included in work zones and the traffic configurations to be used during the execution of these interventions. This requires taking into consideration the costs related directly to the objects, such as the manual labour to execute the interventions, and the costs related to the use of the network, e.g. increased noise and increased accidents due to deviated traffic around the work zone that includes the interventions. It also requires balancing the increase in costs during, and the decrease in costs following, the execution of the interventions.

Grouping together multiple interventions in a work zone can often lead to the reduction of costs related to the execution of the interventions, e.g. the costs of installing a traffic configuration for two objects is not twice as much as for one object. It also, however, requires the explicit consideration of spatial constraints, i.e. the length of the work zone, and the distance between work zones, in addition to cost constraints, such as the available budget.

Although considerable work has been focused on the determination of the optimal interventions to be executed on road networks over the last few years (e.g. the optimal scheduling of resource allocation [1], [2], the optimal scheduling of specific interventions [3], [4], and the optimal scheduling of interventions at the network level [5], [6]), there has been very little research focused on the optimal grouping of interventions in work zones, herein referred to as optimal work zones (OWZs). Some of the works, however, include that by [7]–[10].

The work done by Hajdin & Lindenmann 2007 is the specific starting point of the work presented in this paper. They proposed a network model to determine OWZs for road infrastructure, in which the nodes were used to represent the ends of a physical object with an intervention, and the edges were used to represent the impacts of travelling from one end of the object with an intervention to the other end of the object with an intervention. They illustrated the model by determining the OWZ on a highway network comprised of 567 objects. The weaknesses of the proposed model are its suitability to be used for larger networks, its inability to be used to determine multiple OWZs simultaneously, and its inability to be used to determine OWZs that span multiple time periods.

The model presented in this paper is an enhancement on the one proposed by [7] as it can be used to determine an optimal set of work zones, simultaneously. This is done by reformulating the structure of the cited model, developing a new routing algorithm the allows all possible combination of work zones instead of manually editing the possible work zones, which is impossible to perform for network with hundreds of objects, formulating a new constraint that allows a distance minimum between the consecutive work zones in the network.

# MODEL

## Terminology

A road network is considered to consist of road segments. Each segment is a serial combination of different infrastructure objects (e.g. a road section, a culvert, a bridge, a tunnel). Due to deterioration, the physical condition of objects deteriorate over time and interventions must be executed in order to ensure that the network is able to provide an adequate level of service (LOS). There are different types of interventions that can be executed on each object in the network. For example, a road section can be renewed or can be upgraded with partial depth repair. This concept is summarized in Table 1.

Table 1: Hierarchy of road segments, objects, interventions

|  |  |
| --- | --- |
| Objects | Interventions |
|  |  |
| *N*: Total number of infrastructure objects | *Kn*: Total number of interventions on object *n* |
| refers to “do nothing ” intervention |

In the model, each node represents a specific road segment. The node also represents an intevention to be executed. The edge represents the change in intervention type that occurs between the two objects. This hierarchy makes it easy to use to relate the attributes of one model element to another. Example attributes are given in Table 2.

Table 2: Attribute types

|  |  |  |
| --- | --- | --- |
|  | Type | Examples |
| nodes | Road segment | Length, number of lanes, DTV, type of infrastructure (e.g. tunnel, bridge, etc.), CS |
| Intervention type | Costs (e.g. CHF/m2), improvement in CS (e.g. from CS 4 to CS 1), production capacity (e.g. m2/day) |
| Traffic configuration | Travel speed, change in accident rate, work space per meter of road (as a result of closing one or more lanes) |
| links | Connection | Specific attributes that result from a change in intervention, e.g. costs for traffic jam at the beginning of a work zone, higher accident rates resulting from the change of the intervention |

## Formulation

### Model

#### Objective function

The OWZ is found with the following objective function:

|  |  |
| --- | --- |
|  | (1) |

where

|  |  |
| --- | --- |
|  | is a binary variable, which has a value of 1 if an intervention of type *k* is executed onroad segment *n* and 0 otherwise. |
|  | is the long term benefit of executing an intervention of type *k* on object *n*. |
|  | is the cost of executing an intervention of type *k* on object *n*. |
|  |  |

#### Integrity constraint

|  |  |
| --- | --- |
|  | (2) |

Constraint (2) ensures that only one intervention of type *k* is selected for road segment *n*.

#### Budget constraint

|  |  |
| --- | --- |
|  | (3) |

where

|  |  |
| --- | --- |
|  | is a the total budget allowance on the investigated period. |

#### Maximum length of a workzone

|  |  |
| --- | --- |
|  | (4) |

where

 is the length of the road segment [*l,n*];

 is the first road segment of the WZ , and road segment  is the last road segment in the WZ .

 is maximum allowable length of the WZ.

#### Minimum distance between consecutive work zones

The minimum distance between two worksites has to be greater or equal to a network and/or road type specific value .

|  |  |
| --- | --- |
|  | (5) |

Where object  is the first object of the default section  and object  is the last object in the default section . Every network has a number default sections . A default section is defined as all objects physically connected to each other with being in the default intervention type.

### a routing algorithm

In order to implement two constrains in Eqs. (4) and (5), an routing algorithm is developed so as the two constraint can be simplified into one constraint as follows.

|  |  |
| --- | --- |
|  | (6) |

Where  is a matrix of size (IxJ) , where I is the total number of rows, and each row is the combination of objects that cannot be selected simultaneously.

An example of this matrix is given in following table.

# EXAMPLE

## Overview

In this example the OWZ for a road network consisting of 567 objects in the Canton of Wallis, Switzerland, where each road segment consists of one object. The geographical representation of the choosen network is shown in Fig. 1.



Fig. 1: physical road network

For demonstrating the applicability of the model, we assume that on each object, there are three types of intervention

* Intervention 0: (Do-nothing) Nothing will be executed on the object
* Intervention 1: (lower benefit): A physical intervention is executed but results in low long term benefit
* Intervention 2: (high benefit): A physical intervention is executed but results in high long term benefit

## Condition states

All objects are considered to be in one of five discrete condition states (CS): CS 1 - 5 indicate increasingly poor CSs, where CS 1 is the best condition and CS 2 is the worst condition.

## Interventions

## Model

The model of the intervention for the partial network, where a node represents a possible intervention for a road segment, is shown in Fig. 2. The node number are comprised of two parts (XX.YY). XX indicates the physical road segment, YY indicates the intervention for that object.

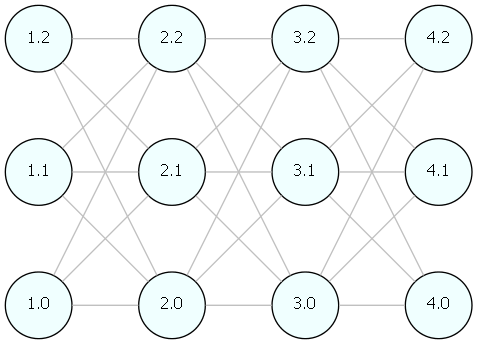


Fig. 2: Nodes and links representing the possible interventions

For example, the YY = 0 in the node reference indicates an intervention of type 0 (which is equivalent to “do-nothing”), whilst, Y = 1 in the node reference (e.g. nodes with XX = 1) indicates an intervention of type 1.

## Scenarios

In order to investigate the effect of budget and work zone length constraints, four scenarios were investigated (Table 4). The objective in each case was the same, i.e. to determine the OWZs.

Table 4: Descriptions of scenarios

|  |  |  |  |
| --- | --- | --- | --- |
| Scenarios | Budget [ mus] | (km) | (km) |
| 1 | 50 | 5 | 5 |
| 2 | 50 | 5 | 8 |
| 3 | 40 | 6 | 8 |
| 4 | Unlimited | 5 | 8 |

## Results

The optimal results for four scenarios were obtained after running the optimization models on each scenario. A summary of the values of objective function, numbers of objects to have intervention and number of work zones given in Table 5.

Table 5: Optimal solutions

|  |  |  |
| --- | --- | --- |
| Scenario | Total benefits  (mus) | Number of objects |
| 1 | 483 | 23 |
| 2 | 456 | 29 |
| 3 | 386 | 17 |
| 4 | 872 | 176 |

Illustrations of optimal work zones for a partial link contains 13 objects corresponding to four scenarios are given in Fig. 3-Fig. 6.



Fig. 3: Optimal work zone - scenario 1



Fig. 4: Optimal work zone - scenario 2



Fig. 5: Optimal work zone - scenario 3



Fig. 6: Optimal work zone - scenario 4

# CONCLUSION

In this paper a linear mixed integer optimization model to be used for determination of optimal work zones for a transportation network composed of a large number of infrastructure objects has been proposed. It has an advantage over the previous research that it enables the determination of optimal work zones taking into consideration of both maximum length of each work zone and minimum distance between adjadcent work zones. Budget constraint is also included in the model.

In order to cope with a large scale network when building the data matrix, a routing algorithm has been developed that allows a robust and efficient formation of combination matrix to be used as an input of the optimization model.

The model was tested with a roat network in the Canton of Vallis, Switzerland that includes 567 objects of different types of infrastructure (e.g. bridge, tunnel, and road). In the example, GIS data of the network was ultilized and three categoris of road was selected: highway road sections; primary and secondary road sections that belong to a Cantonal network. Three types of intervention were imposed on each object (do-nothing, low benefit, and high benefit interventions). Estimation results show that the model is efficient and can be used for large network.

Future study is required to extend the model to deal with the nonlinearlity when there is a combination of intervention and traffic configuration (e.g. the suddent switch of traffic configurations between two objects and between work zones. In addition, multiple planning period should be included in the model.

# REFERENCES

[1] B. F. Kallas, “Pavement maintenance and rehabilitation,” 1985.

[2] B. Adey, A. A. Khaled, M. M. Maher, P. L. Durango-Cohen, R. Guido, H. Rade, A. Bryan, B. Eugen, C.-Y. Y. Chu, D. M. Frangopol, M. J. Kallen, J. M. V Noortwijk, G. Roelfstra, R. Hajdin, E. Brühwiler, and J. O. Sobanjo, “Probabilistic Models for Life-Cycle Performance of Deterioration Structures: Review and Future Directions,” *ASCE Conf. Infrastruct. Manag. Plan.*, vol. 6, no. 1, pp. 17–32, Feb. 2004.

[3] Y. Wang, R. L. Cheu, and T. F. Fwa, “Highway maintenance scheduling using genetic algorithm with microscopic traffic simulation,” in *Proceeding of TRB 81st Annual Meeting*, 2002.

[4] B. Adey, T. Herrmann, K. Tsafatinos, J. Luking, N. Schindele, and R. Hajdin, “Methodology and base cost models to determine the total benefits of preservation interventions on road sections in Switzerland,” *Struct. Infrastruct. Eng. Maintenance, Manag. Life-Cycle Des. Perform.*, vol. 8, no. 7, pp. 639–654, 2010.

[5] A. Ferreira, L. Picado-Santos, and A. Antunes, “A Segment-linked Optimization Model for Deterministic Pavement Management Systems,” *Int. J. Pavement Eng.*, vol. 3, no. 2, pp. 95–105, 2002.

[6] N. Sathaye and S. Madanat, “A bottom-up solution for the multi-facility optimal pavement resurfacing problem,” *Transp. Res. Part B Methodol.*, vol. 45, no. 7, pp. 1004–1017, Aug. 2011.

[7] R. Hajdin and H. P. Lindenmann, “Algorithm for the Planning of Optimum Highway Work Zones,” *J. Infrastruct. Syst.*, vol. 13, no. 3, pp. 202–214, 2007.

[8] ERA-NET, “Stakeholders Benefits and Road Interventions Strategies,” 2012.

[9] C. H. Chen, P. Schonfeld, and J. Paracha, “Work zone optimization for two-lane highway resurfacing projects with an alternate route,” *Transp. Res. Rec.*, vol. 1911, pp. 51–66, 2005.

[10] Y. Chang, O. B. Sawaya, and A. K. Ziliaskopoulos, “A Tabu Search Based Approach for Work Zone Scheduling,” in *Proceeding of the TRB 80th Annual Meeting*, 2000, no. 01–2950.