Advances in Intelligent Systems and Computing 262

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Computer-based Modelling and Optimization in Transportation

Springer

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ISSN 2194-5357 ISSN 2194-5365 (electronic)
ISBN 978-3-319-04629-7 ISBN 978-3-319-04630-3 (eBook)
DOI 10.1007/978-3-319-04630-3
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014932286

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

This volume brings together works resulting from research carried out by members of the EURO Working Group on Transportation (EWGT) and presented during meetings and workshops organized by the Group under the patronage of the Association of European Operational Research Societies in 2012 and 2013.

The main targets of the EWGT include providing a forum to share research information and experience, encouraging joint research and the development of both theoretical methods and applications, and promoting cooperation among the many institutions and organizations, which are leaders at national level in the field of transportation and logistics.

The primary fields of interest concern operational research methods, mathematical models, and computation algorithms, to solve and sustain solutions to problems mainly faced by public administrations, city authorities, public transport companies, service providers, and logistic operators. Related areas of interest are: land use and transportation planning, traffic control and simulation models, traffic network equilibrium models, public transport planning and management, applications of combinatorial optimization, vehicle routing and scheduling, intelligent transport systems, logistics and freight transport, environment problems, transport safety, and impact evaluation methods.

In this volume, attention focuses on the following topics of interest:

- Decision-making and decision support
- Energy and environmental impacts
- Urban network design
- Optimization and simulation
- Traffic modeling, control and network traffic management
- Transportation planning
- Mobility, accessibility, and travel behavior
- Vehicle routing

The complexity of the problems analyzed made it difficult to give a complete picture of the above aspects but, in the opinion of the editors, the works presented here will help readers to go more deeply into some significant subjects with the aid of experts' viewpoints of the problems. The high standard of the papers submitted was ensured by a large and competent scientific committee and by a selective reviewing process.

To end this preface, special thanks go to all those who contributed to this book, including authors, reviewers and Springer, and in particular to Dr. Thomas Ditzinger (Springer, Applied Sciences and Engineering).

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Contents

Part I
Decision Making and Decision Support (in Transportation)

In the transportation field—as in many others—it is important to be able to guarantee that the *decision-making* has been systematically followed, to ensure that the right decisions are taken. Identifying needs, checking the availability of resources, formulating frameworks of analysis, and evaluating methods are just some of the aspects involved in this process, often reinforced by *decision support* techniques. *Hankach and Lepert* introduce a decision support tool for evaluating maintenance strategies on road networks with incomplete data. *Ambrosino and Siri* provide a general formulation for proper train load planning for maritime container terminals, as well as two other formulations for specific cases in which some unproductive operations or movements are not permitted. *Haasis et al.* develop a rule-based decision support system for improving the energy efficiency of passive temperature-controlled means of transport, and apply it to the case of liquid aluminium transport in Germany. *Bandeira et al.* present an integrated numerical computing platform, using microscopic traffic and emission models, as a tool for traffic assignment taking into account eco-routing purposes: the main aim of this work was to identify the best traffic volume distribution which allows the environmental costs for a given corridor with predetermined different alternative routes to be minimized. *Mendes-Moreira and Freire de Sousa* discuss evaluation of the impact of changes, before they are made, in global operational planning in real-life conditions, and present a framework for their evaluation.

A Decision Support Tool for Evaluating Maintenance Strategies on Roads Networks with Incomplete Data

Pierre Hankach and Philippe Lepert

Abstract Choosing a maintenance strategy is a major challenge for road operators because of its implications on the required budget and the quality of the road network. However, a major problem has to be solved before we can compare the performance of different strategies: on many real networks, essential data for simulating the evolution of the distress of the pavement for the coming years and hence simulating the strategies in order to evaluate them, are missing or highly uncertain. In this chapter, we introduce a decision support tool for evaluating maintenance strategies on roads networks with incomplete data. First, this tool is used to build a Virtual Road Network (VRN) that represents the real network, and on which plausible values are allocated to missing or uncertain data. Then, it is used to simulate alternative strategies. To this end, the distress state of the pavement is evolved using an appropriate evolution model and each strategy is applied in order to determine the associated maintenance interventions. The different strategies are thus compared (on the network scale) on the criteria of cost and resulting distress state of the pavement in order to choose the best solution.

Keywords Pavement · Damage · Distress · Maintenance · Strategies · Simulation · Evolution models · Network

1 Introduction

Defining a maintenance strategy is a very important task for road mangers. In fact, both the condition of the road network and the required maintenance budget depend on the chosen strategy. Therefore, evaluating and comparing the cost and

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J. F. de Sousa and R. Rossi (eds.), *Computer-based Modelling and Optimization in Transportation*, Advances in Intelligent Systems and Computing 262,
DOI: 10.1007/978-3-319-04630-3_1,

performance of different strategies is an essential step in maintenance management. In this chapter, we present a decision support tool in order to evaluate strategies and choose an adequate one.

A maintenance strategy is a set of rules that define when a maintenance intervention is triggered and the design and technique of this intervention. Strategy rules that trigger interventions are usually based on the extent of the distress and other parameters such as the date of the last intervention. In order to evaluate a strategy, the distress must be computed annually simulating its evolution for the coming years starting from the present date and present condition of the pavement. Whenever a maintenance intervention is triggered by the strategy, the condition of the network is updated accordingly and taken into account for its future evolution. Therefore, the condition of the pavement at a given date in the future is determined by combining the evolution of distress and the effect of maintenance interventions. The cost of maintenance associated to a strategy is the sum of the costs of individual interventions that it triggers.

However, a major difficulty must be addressed in order to simulate a strategy and evaluate it: essential data for this process are missing in real road network databases. As it have been pointed, the distress state of the pavement must be evolved for simulating a strategy and this evolution depends on different factors: pavement design, resistance of materials to cracking, aggressivity of the traffic, etc. It can be expressed by the following formula:

$$\%Ff = \Phi(t\,;\,\alpha\,;\,\beta\,;\,\gamma\,;\,\delta\,;\ldots) \tag{1}$$

where Φ is a complex formula in which t represents the time elapsed since the construction and $\alpha; \beta; \gamma; \delta; \ldots$ represent the factors that influence the evolution. In virtually all road databases describing real networks, the latter variables are missing. There is therefore no possibility of applying an evolution model that takes into account these factors without addressing the missing data problem.

In this chapter, we build a decision support tool for evaluating maintenance strategies. First, the problem of missing data on roads networks is handled by building a VRN that represents the real network, and on which plausible values are allocated to missing or uncertain data. Afterwards, in order to evaluate maintenance strategies, the distress is computed year after year using a distress evolution model, triggering maintenance interventions by strategy rules. The consequences of each strategy are assessed on the future distress state of the network and on the required maintenance budget. Thus, different strategies can be compared.

2 Constructing the Virtual Network (VRN)

A virtual road network is a road database comprising: (1) a list of roads; (2) a reference system and (3) a set of data describing the nature and condition of the roads and their solicitation. As previously stated, the information and data contained in the database of a virtual network are generated according to certain rules and/or by applying certain models in order to accurately represent the real network. Hereafter, the rules followed for creating a virtual network are listed:

- The constitution of the network (number of roads, length) is identical to that of the real network;
- Roads are divided into segments of homogeneous subgrade characteristics. The length of each segment and its characteristics are random samples from the probability distributions of these parameters on the real network (which may be known from the examination of a number of design projects);
- If the traffic on the real network is not known and therefore cannot be assigned directly, each road is divided into segments of homogenous traffic (that are different from the segments mentioned in the previous point). The length of each segment and its traffic are random samples from the probability distributions of these parameters on the real network (obtained by performing a sampling on the latter);
- The pavement design is homogenous per segments that correspond to the original construction segments. Each segment's length is a random sample from a predefined probability distribution that reflects reality. The structure of the segment is chosen according to the characteristics of the subgrade and the traffic that will be supported, as is the case in a conventional design process. These inputs are used to select structures types in a design catalog [1]. The distribution of the types of structures obtained is validated by comparing to the distribution on the real network (obtained by sampling).

In the remainder of this section, we describe the construction of a virtual network. We take the French national road network (FNRN) as a reference real network to illustrate this construction.

2.1 Constitution of a VRN

The VRN is constituted by all the roads of the real network. In order to locate events—such as distress—on the roads, we associate to the network a linear referencing system. Each road is associated with a unique identifier and a number of location points (PR). The position of the various objects on the road is expressed with respect to these points. For practical reasons, roads are segmented into elementary sections of fixed length (typically 200 m). Each section is identified by specifying the "PR + distance" of its start and end points. In the remainder of this chapter we use as building blocks these sections in order to affect different characteristics.

2.2 Attribution of the Bearing Capacity of the Subgrade

The pavement thickness design depends on the bearing capacity (PF) of the platform. This bearing capacity is classified into four groups (PF1, PF2, PF3 and PF4) according to the subgrade's ability to withstand loads. In the process of building the VRN, we assign each section a bearing capacity selected from these four classes. To perform this assignment, two distributions must be defined in advance from sampling performed on the real network:

- The first distribution governs the length of the pavement segments where the bearing capacity is considered homogeneous. The length of each segment is a random sample from a triangular distribution. To reproduce conditions similar to those of the FNRN, the triangular distribution is defined with a minimum of 1 km, a maximum of 5 km and a mode of 2 km.
- The second governs the distribution of bearing capacity classes. Because this distribution wasn't available for the FNRN, the bearing capacity of each homogenous segment is chosen randomly among the four classes. In the case where the distribution between the four classes is known, it should be respected.

2.3 Attribution of the Traffic

The following procedure is applied when the traffic and/or its aggressivity is unknown on all or a part of the network. Like for the bearing capacity, the assignment of traffic on a virtual network is defined in two steps. First, the road network is divided into segments of homogeneous traffic. Then, for each of these segments, the daily vehicle average is defined for each category (cars, trucks…) as random samples from predefined probability distributions. These latter distributions are defined by experts, and reflect the state of the traffic on the real network. In order to reproduce traffic conditions similar to the FNRN the following distributions are used:

- The length of each segment is defined as a random sample from a triangular distribution with a minimum of 5 km, a maximum of 25 km and a mode of 15 km.
- The daily vehicle average is defined as a random sample from a triangular distribution with a minimal traffic of 0 vehicles per day (v/d), maximum traffic of 80000 v/d and a mode 30000 v/d.

In recent design methods, thickness design of pavements depends on the traffic class TCi which takes into account the lifespan of the pavement. The traffic class is determined by the total number of heavy traffic (which is a predefined proportion of the total traffic) that will be supported by the pavement during its lifetime. This lifetime is generally set at 20 years, and is extended to 30 years for pavements supporting high traffic. Traffic classes TC are obtained using the following formula [2]:

$$TC = 365N\,.\left[d + \tau\,.\,d\,.\left(\frac{d-1}{2}\right).\,r\right] \quad (2)$$

where N is the heavy traffic count; τ the linear annual growth rate of traffic rate (2 % by default); d the lifespan in years; and r represents the transversal distribution of heavy traffic. According to the value of TC, the traffic is attributed one of nine classes: TC0, TC1, TC2, TC3, TC4, TC5, TC6, TC7 or TC8.

2.4 Thickness Design

The thickness design of a pavement segment of the VRN is made using the same rules applied for the construction of a real network. It depends on the bearing capacity of the subgrade and the traffic class as described in [2].

The length of segments with a homogenous design results from the length of construction segments. To reproduce the conditions of the FNRN, it is defined as a random sample from a triangular distribution with a minimum of 5 km, a maximum of 25 km and a mode of 15 km. As each construction intervention occurs at a given date, it also defines the age of the pavement.

The pavement design of a segment is given as a function of the bearing capacity of the subgrade and the traffic (Table 1). However, on a single construction segment a multitude of combinations "bearing capacity class/traffic class" are usually identified. Figure 1 shows the diversity of this combination for one construction segment. Given this fact, the design that corresponds to the largest traffic coupled with the smaller PF is chosen. This rule ensures the selection of the stronger design among those that correspond to the various combinations.

3 Evaluating Maintenance Strategies

A maintenance strategy [3–5] is a set of decision rules that determines, mainly based on the condition of a pavement's section, its age, traffic or any other criterion available in the database: the work to be done on this section; the design of the maintenance works; and the priority given to it. Table 2 illustrates a very simple strategy based on the IRI (International Roughness Index). It stipulates that if IRI < 5 then no maintenance intervention is necessary, otherwise an overlay is performed. Usually, strategies are much more sophisticated and rely on many indicators to compute maintenance. Table 3 illustrates a strategy that defines maintenance interventions depending on both the IRI and the percentage of cracks extent.