THE INFLUENCE OF INITIAL DESIGN AND CONSTRUCTION STANDARDS ON THE LONG-TERM INFRASTRUCTURE PERFORMANCE

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Abstract

The performance throughout the lifetime of an infrastructure is in part influenced by factors that are decided upon during the period of initial provision. The objective of this thesis is to explore the sensitivity of infrastructure performance to changes in initial design and construction standards.

After the presentation of the conceptual framework, two approaches are explored via two case studies:

- an aggregate cost-based approach explores the sensitivity of maintenance expenditures to initial provision costs for Light Rail infrastructure;
- a disaggregate deterioration-based approach models performance outcomes as a function of initial provision variables for highway bridge decks.

Finally, the applications of the methodologies to Cost Benefit Analysis and Contract Design and Monitoring are discussed, with specific examples related to Tren Urbano.

Key Words
Infrastructure; Light Rail; Bridges; Deterioration; Tren Urbano.

The main **objective** of this thesis is to determine the extent to which infrastructure performance is sensitive to initial conditions. It shows which decisions matter in the earlier phases of a project by determining the impact of changes in the initial conditions on the long-term infrastructure condition state by placing emphasis on the significance, magnitude and direction of this impact.

The lifetime of an infrastructure often extends to as much as 50 years; sometimes even more. Initial provision decisions, in addition to determining design and construction costs, affect deterioration rates and maintenance needs. Deterioration increases the maintenance required and, consequently, the corresponding cost the agency incurs in operating the system. Also, deterioration affects user costs and benefits by reducing the quality of service received by the users. There are, hence, two dimensions to the problem of interest. On the one hand there is an aggregate perspective that considers the economic dimension and relationships amongst the costs and benefits associated with the various decisions and activities. On the other hand, there is a more disaggregate perspective that explicitly considers the deterioration process itself.

The factors that, among others, affect the deterioration process, are the following:
-Design standard;
-Construction technique and quality;
-Maintenance and rehabilitation;
-Usage levels;
-Environment.

Infrastructure deterioration is in general non-linear: the deterioration rate increases as the facility ages.

In the initial phases of development a trade-off needs to be assessed between initial quality and costs on one side and performance and maintenance expenditures on the other.

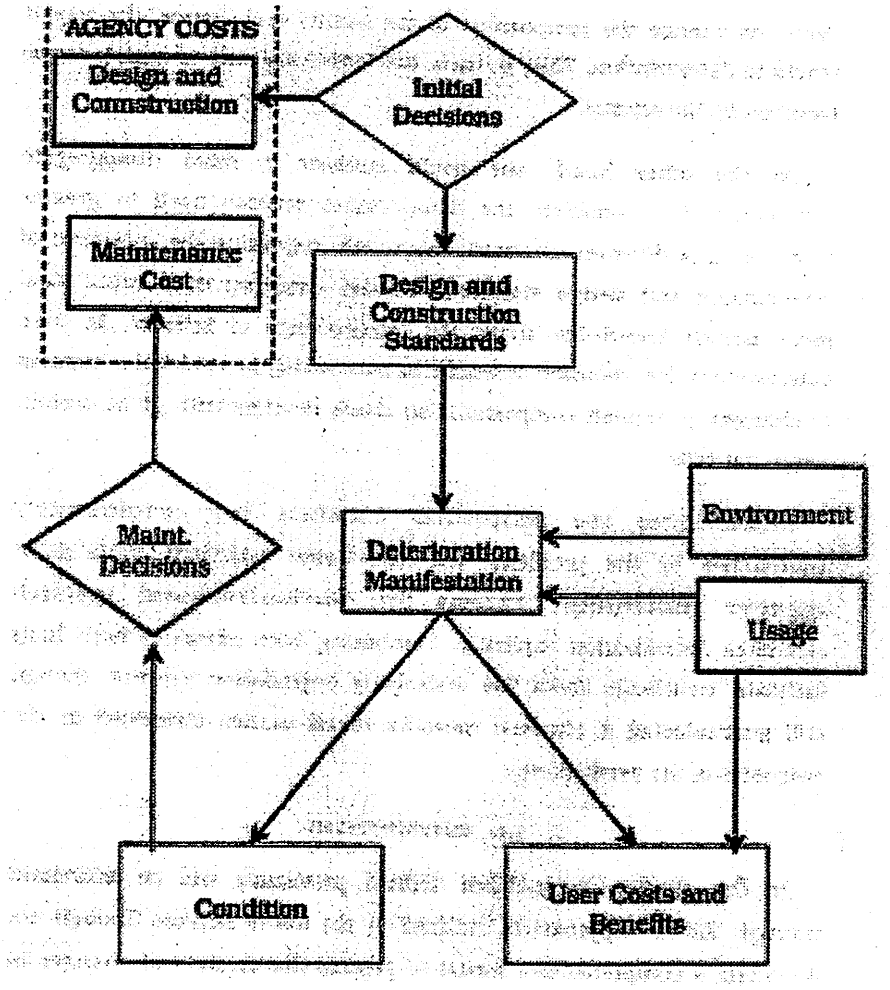

Figure 1

The Figure above shows the infrastructure performance framework assumed in this thesis. Two complementary approaches are possible:

- from an aggregate perspective, the two cost extremes of the framework are considered, so as to predict how a change in the decision process influences user and agency costs;
- a more disaggregated perspective considers the deterioration process in greater detail.

The conceptual framework is explained in **Chapter 2**. Particular attention is paid to the relationships between infrastructure provision and management decisions, physical process and costs, synthetically illustrated in the following Figure.

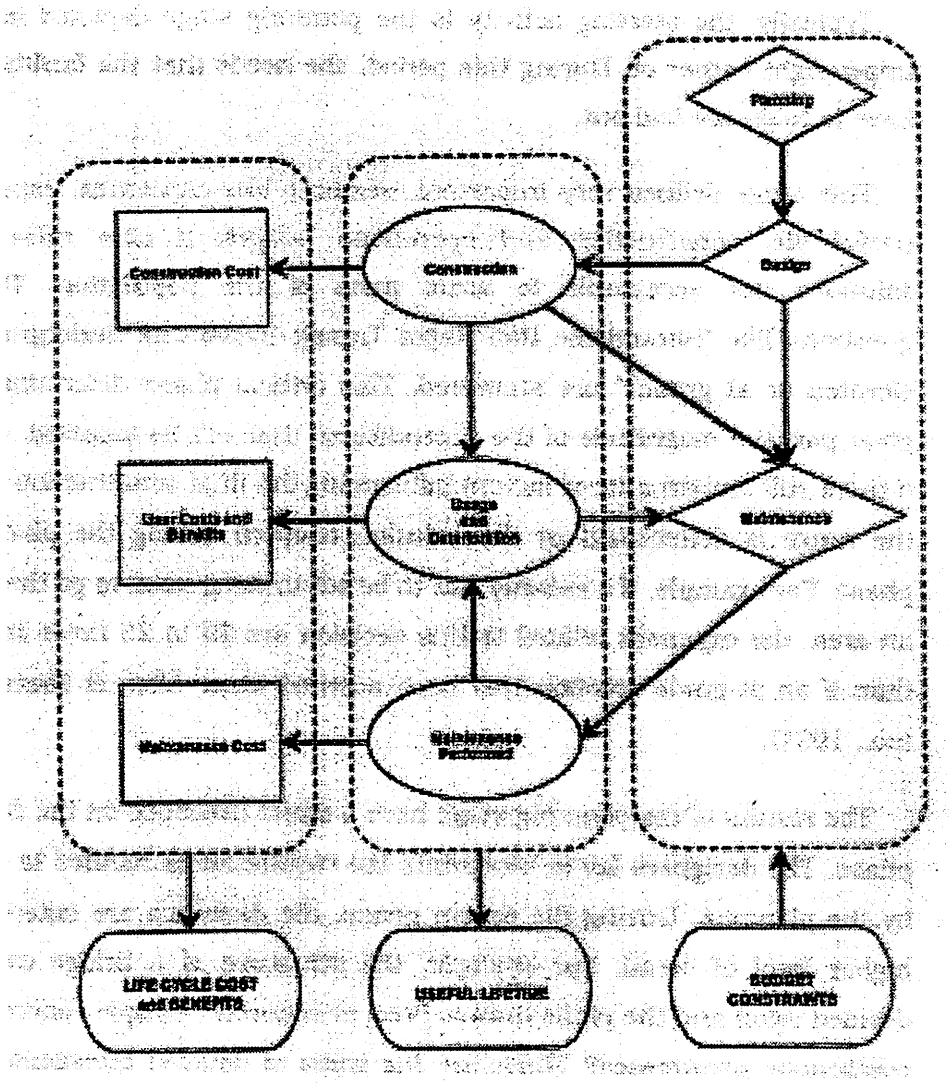

Figure 2

The assessment of infrastructure related expenditures over time is done according to the Life-Cycle costing (LCC) technique (page 31). A sensitivity analysis approach is adopted to assess the impact of initial infrastructure conditions on the long-term performance of a facility (page 32).

Chapter 3 presents the Cost-based approach. Based on a Light Rail case study, this analysis is geared at providing a broad perspective on the problem. The data are gathered from the Light Rail systems of Los Angeles, Pittsburgh, Portland, Sacramento and San Jose'. This approach is based upon two major assumptions:

- that design and construction cost variables are good proxies for quality;

- that maintenance activities and consequently costs respond to the needs of the system, mirroring its condition.

It presents the aggregate picture of the deterioration process, relating yearly maintenance expenditures to changes in initial capital costs. Rail deterioration is presented through the types of failures that typically occur, the maintenance practices to alleviate this deterioration and a discussion about the relevance to passenger rail. The methodology is based on a multivariate regression model to relate performance with design and construction standards. Most results are in accordance with the a-priori expectations: the more is spent on construction, i.e. the better the quality, the lower the maintenance expenditures are later on. Some though are not: notably, elevated construction costs show a positive association with maintenance expenditures, due to the difficulties to integrate elevated structures in an urban contest which in its turn translates into complexity of design and construction that pose additional constraints on maintenance activities. Finally, this chapter describes a number of limitations to this approach.

These results are complemented by the Deterioration-based approach presented in **Chapter 4**. Relying on a Highway Bridge-Deck case study, this more detailed analysis links causal variables to deterioration over time. This is aimed at providing more explicit insight into the deterioration process itself. Because of lack of deterioration data on Rapid Rail systems, a parallel is drawn with another infrastructure system where condition is closely monitored, namely highway bridges. Because there is no immediate parallel as far as conclusions that can be drawn between the bridge deck and the track deterioration, this part of the research focuses on demonstrating the approach and arriving at general conclusions. The chapter offers a background on bridge deterioration as well as on construction materials and techniques with references to previous studies. Four major variables are considered: initial condition variables, temporal decision variables, uncontrollable temporal factors, and output variables. The following Figure illustrates the conceptual framework for Experimental Design.

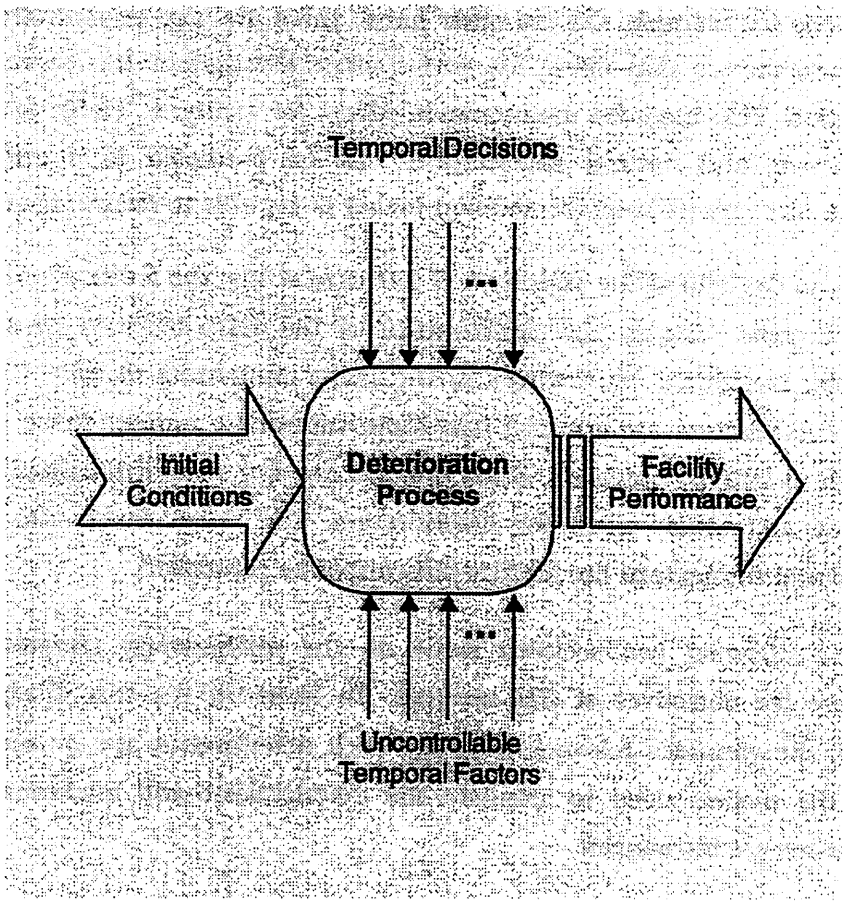

Figure 3

Among the initial condition variables are:
- Wearing Surface type;
- Structure types;
- Number of Spans;
- Span length;
- Skewness of Main Span with respect to the approach roadway;
- Deck width;
- Initial Quality of Construction;
- Road type.

Among the uncontrollable temporal factors are:
- Bridge Age;
- Average Daily Traffic;
- Climatic conditions.

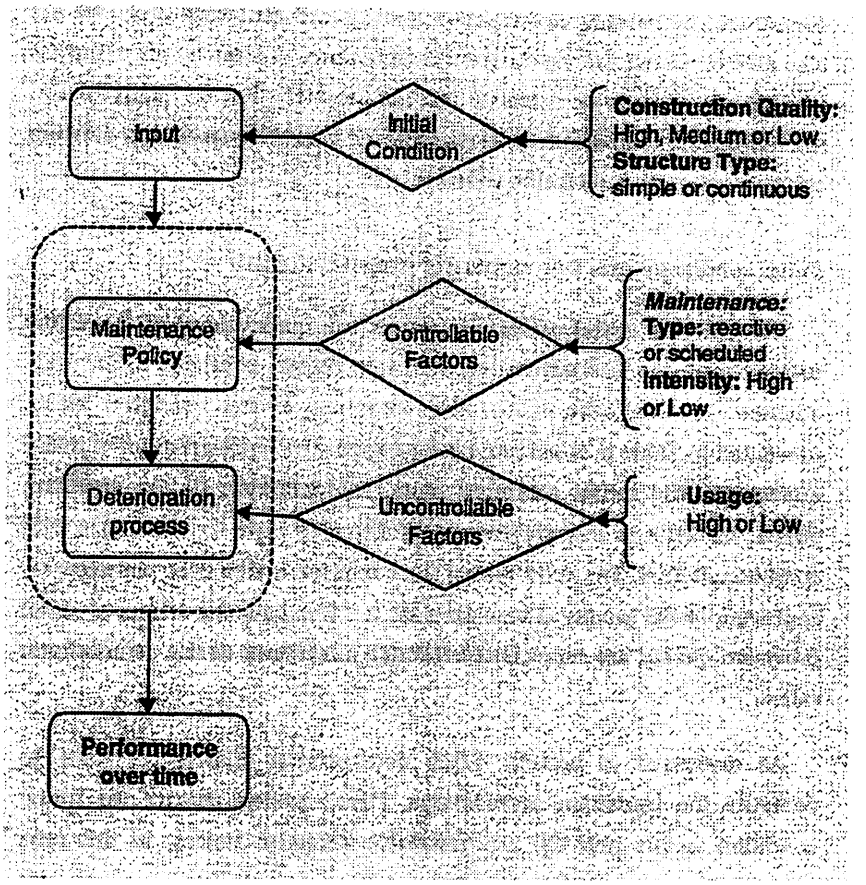

Figure 4

The above figure presents how each variable type impacts the deterioration process. The rightmost column features the dimensions that we are varying when defining the scenarios. The center column presents the category to which the variables belong. The leftmost column features the elements the categories influence.

The author has chosen a number of scenarios, built around the variations of specific variables, to demonstrate the methodology and arrive at sufficient results. The findings confirm that initial quality has an impact on the outcome. However, sensitivity to initial quality is greater when maintenance is at a higher standard. When a facility is subject to a low maintenance policy, it deteriorates at a faster rate. This deterioration seems to reduce the differences that exist between facilities with different initial qualities. With respect to the type of structure, though, the interactions are quite different. The structure type seems not to influence the sensitivity to initial quality. Bridge deck condition is also proven to be significantly impacted by maintenance policies. Traffic and structural type play a lesser role in determining the deterioration rates of the facility. The better the condition of the facility, the more it is sensitive to these influential factors. Pursuing the deterioration-based approach the

thesis demonstrates the value this methodology and its applicability to different infrastructures. It also contributes to the understanding of the deterioration process and the variables affecting it.

In **Chapter 5** the possible applications of the results are discussed. The Tren Urbano context is used to give more concrete examples. The applications of the findings of this thesis fall into two main categories. The first one, Cost Benefit Analysis, is dealing with the economic aspect of the problem. These applications are relevant to Tren Urbano because of the many design phases that remain to execute. Another application is the contract monitoring aspect that can be successfully implemented with the input from good condition assessment and prediction. This is particularly important in contexts where several actors with different goals are working on the same project. The methodologies developed in this thesis allow for anticipating the many consequences of initial provision decision in terms of level of service and operating costs. In this way it offers all parties elements upon which they can base their contracts and monitor their performance. In the case of Tren Urbano, since the Design, Construction, Operation and Maintenance activities are contracted out to a private consortium, the government needs to be assured that its long-term goals are respected. Therefore, developing the tools for clearly defining the responsibilities of each party would be a great benefit.

Chapter 6 summarizes the conclusions of the research and presents future extensions and directions for further research in this area.

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