A Systems Approach for the Development and Management of Physical Infrastructure

Dr D.S. Thorpe

Queensland Department of Main Roads, Australia
E-mail: David.S.Thorpe@MainRoads.qld.gov.au

ABSTRACT: *A methodology has been developed for modelling physical infrastructure life cycle development and management. It is based on a combination of flowcharting and analysis techniques, and maps infrastructure life cycle processes over time using a data flow approach, in which these processes are divided, over the infrastructure life cycle, into modules connected by information flows. This methodology is being adapted to constructing a framework for evaluating the options in the development and management of low volume roads in remote areas. Traditional techniques do not well evaluate these options, and the framework is aimed at providing an alternative for doing so.*

Keywords: *Systems thinking, life cycle, infrastructure, management, roads.*

INTRODUCTION

Physical infrastructure assets, such as roads, are likely to represent major financial investments, be designed to last for many years, be heavily used, carry considerable load, and be exposed to the natural environment.

Increasingly, it is becoming apparent that the individual processes in infrastructure development and management should not only be performed well and efficiently, but also be combined as a whole to provide the best overall outcome for the various stakeholders.

In this life cycle view of infrastructure development, the abilities to better understand the effect of inputs in the infrastructure life cycle on results, minimise uncertainty, and better evaluate the effect of decisions in a complex environment, are important in allocating scarce resources and making sound decisions. While there is often no one best management approach, the choice of options is improved by better identification and analysis of the issues, by the ability to prioritise objectives, and by scientific analysis.

Some infrastructure, such as low volume roads in remote areas, provides particular challenges in this respect. The development of such roads may significantly improve social and economic wellbeing for their regions and communities, but may be difficult to justify on a normal economic basis. Hence, for their proper consideration, an evaluation and analysis framework is required that that takes into account their particular requirements.

This paper describes a life cycle modelling and analysis process for infrastructure development and management, and its application to the construction of such a framework.

ISSUES IN INFRASTRUCTURE DEVELOPMENT AND MANAGEMENT

Complexity of the Infrastructure Development and Management Process

The infrastructure manager interfaces with the infrastructure system and a number of managerial sub-systems (Grigg, 1988). Good information links are required for best operation of both the systems and the management process.

A further perspective on the infrastructure development and management process may be obtained by considering Figure 1, which shows a range of factors influencing the development and operation of infrastructure over its life cycle. These factors, which can each be divided into a number of sub-factors, arise not only from the engineering requirements of technology, economics and management, but also from social and political influences such as legislation, social needs, environmental requirements, and the political environment. These diverse requirements need to be taken into account by the modern infrastructure developer and manager.

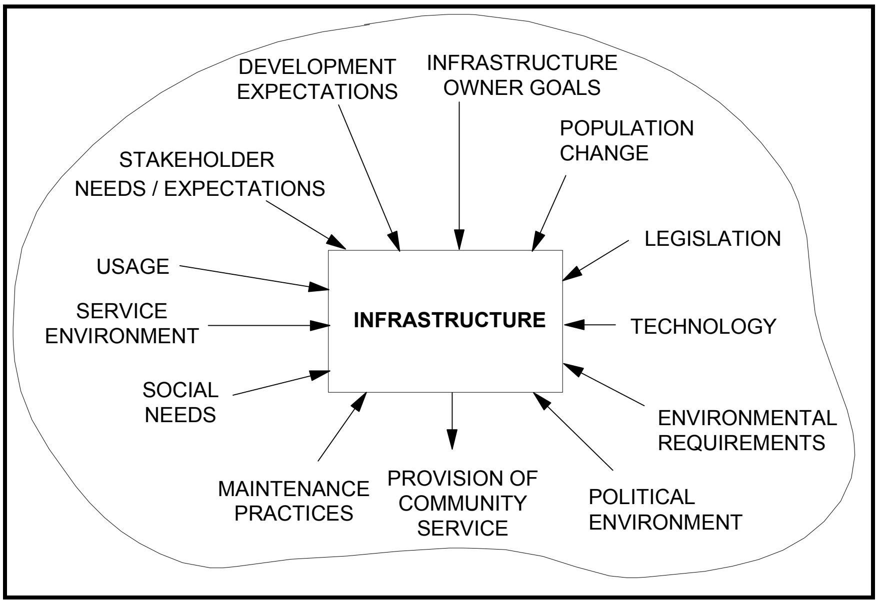

Figure 1 - Components of the Infrastructure Environment

Need for a Strategic View

This complexity of infrastructure development and management, and of the underlying systems and sub-systems, leads to a strategic, integrated view. For example, if infrastructure is to provide an adequate level of service, at minimum whole of life cost, then proper consideration of life cycle issues requires to be given to not only to each of the development activities, such as analysis, design, and construction, but also how these activities interact over the infrastructure life cycle.

In this strategic view, there are a number of considerations in infrastructure development and management. These considerations include the degree of integration that should be used, the management of uncertainty, the need for a number of objectives to be met, and how qualitative variables as well as quantitative variables should be considered. In addition, it is sometimes necessary to understand a process in detail, but at other times it is best if a high level view is taken, and thus there requires to be a balance between overview and detailed levels over the life cycle. Finally, in a situation such as the development and management of low volume roads, there may not be readily available data.

Because of the complexity of infrastructure life cycle development and management, and the requirement to balance integration and modularity, standard decision support approaches such as analytical methods, optimisation techniques, and simulation methods, are not really suitable for modelling the whole life cycle. An alternative approach is therefore required.

METHODOLOGY TO ADDRESS THE ISSUES

Requirements for the Methodology

A methodology to address the above has been developed by the author (Thorpe, 1998, 1999). Based on systems principles, it maps the infrastructure life cycle over time, balances overview and detail, considers uncertainty and deals with multiple inputs and objectives.

This methodology consists of the following main components:

- Select desired life cycle outcomes (this process defines a set of multiple objectives).
- Rationalise and prioritise the selected multiple objectives.
- Consider the main modelling issues, and the likely input factors, as related to objectives.
- Flowchart the infrastructure development process, showing information flows between life cycle elements (collated into modules where appropriate), and where possible their relationships.
- Assign initial values to the input parameters and determine the value of results using the initial parameter values and the relationships between the modules.
- Perform a sensitivity analysis to determine the most significant input parameters in influencing the result, and review for reasonableness.

- Evaluate the effect of variation in input variables on the result, and develop conclusions.

The following sections discuss the special issues of rationalisation and prioritisation of objectives, and development of the flowcharting methodology, or time interaction diagram.

Rationalisation and Prioritisation of Objectives

One method to rationalise multiple objectives, and therefore keep them to a manageable number, may be based on the approach of Kepner and Tregoe (1965, 1981). The adaptation used divides the objectives into MUSTS (mandatory), NOT REQUIRED (which are discarded), WANTS (which are ranked).

A good approach for prioritisng or ranking the WANTS is to use paired comparisons. An example of this approach is the Analytic Hierarchy Process (for example, Saaty and Vargas, 1982), a method which uses mainly qualitative judgments to measure the strength of interactions in a complex environment. An advantage of this approach is that qualitative variables can be included in the analysis. In addition, variables can be arranged in a hierarchy, enabling the contribution of a number of variables to be expressed in terms of a much smaller set of weighted objectives.

In evaluation, each variable may be given a score, based on a constant scale (say, 0 to 5), using an algorithm appropriate to that variable . Qualitative variables may be included in this process using a utility or similar approach.

Time Interaction Diagram (Flowcharting Methodology)

Relationships between variables are developed through the time interaction diagram, which is a flowcharting methodology that charts - over time - the information flows between the steps in the infrastructure life cycle. It also breaks up the infrastructure life cycle into modules, thereby recognising that while it ideally this life cycle should be considered as an integrated whole, practical realities are that there are definite steps in this process, and these steps may be better interfaced with each other rather than integrated.

A time interaction diagram is a logical view of the infrastructure life cycle, aimed at understanding the interactions in the infrastructure life cycle. It is an extension of the data flow diagram principle, using information flows in place of data flows.

The time interaction diagram is combined with a structured systems approach to allow modules to be broken down into varying levels of detail, thereby enhancing flexibility in the process through taking advantage of specialist knowledge in particular parts of the process being modelled, while enabling this specialist knowledge to be taken up to the appropriate level of detail required for overall analysis. Figure 2 illustrates this point through a "bridge" analogy to the infrastructure development process.

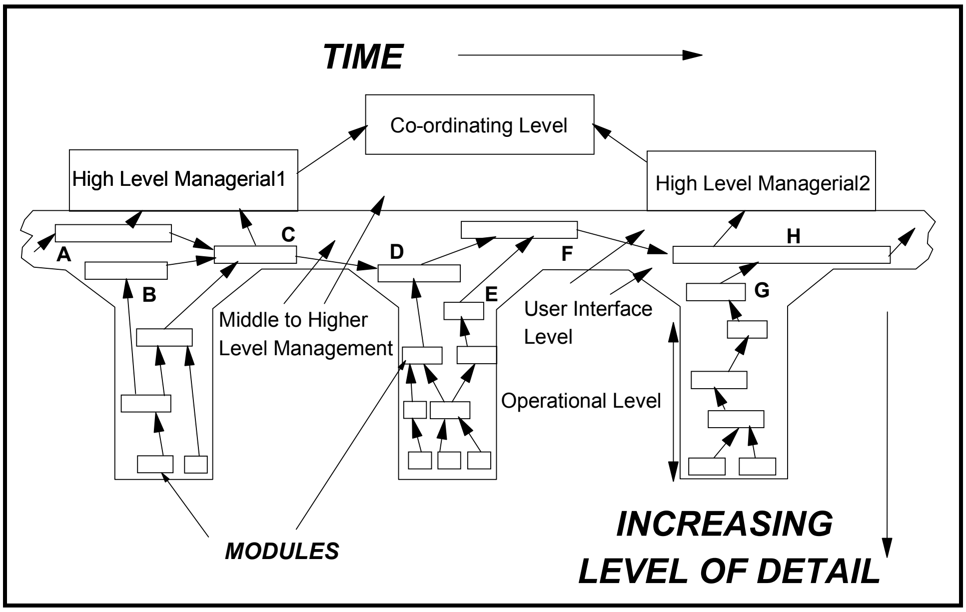

Figure 2 - Illustration of differing Levels of Detail over Infrastructure Life Cycle

A time interaction diagram consists of a combination of static and dynamic internal and external *inputs, outputs, processes* (or tasks), the time *period* into which activities are grouped and by which costs are collected, *relationships* (or connecting equations) between variables, and *stores*, which are items that accumulate during a time period, such as costs, benefits, and operational performance.

Not only does this diagram chart and provide understanding of the interactions in the segment of the infrastructure life cycle under consideration - in this case development and its antecedent and subsequent activities, but also it provides a framework for evaluating the impact of variability in input factors and relationships, either through direct calculation or - where this is difficult - simulation.

APPLICATION TO LOW VOLUME ROADS

Issues with Low Volume Roads

While low volume roads carry low traffic volumes, they play a significant role in the Australian rural transportation system, and especially impact on rural area development and communities in remote areas. Many low volume roads also traverse areas that provide poor natural environments for road building and have a scarcity of good construction materials.

Current low volume road planning and design evaluation does not well consider a number of local community aspects such as potential for economic growth, access, community well being, and potential for tourism. Likewise, the specific design and lifecycle issues involved are difficult to address in a systematic way.

One of the issues facing low volume roads is the best development path for such roads. Options include the "do nothing" option, forming and paving the road only, undertaking a conventional sealed construction, or using advanced technologies such as a geotextile seal on a thin pavement on a stabilised sub-grade. Each has advantages and disadvantages.

Determination of the best development option for low volume roads from a strategic viewpoint can be assisted by a strategic framework to better take into account the specific needs of low volume roads, and which can assist planners, designers and others to prepare the best option for developing and managing these roads.

Application of the Methodology

A strategic framework such as that described above may be developed through adapting the infrastructure lifecycle modelling and analysis methodology described above to evaluation of low volume road development and management options. This adaptation encompasses physical, economic, social, political, legal, cultural and environmental factors under conditions of uncertainty and dynamic change.

The first step in this adaptation has been to identify the objectives and input factors in the development of low volume roads. This step has been followed by refinement of these factors and classifying the inputs with respect to the life cycle phases in which they appear significant. These phases are shown in Figure 3, which shows a high-level time interaction diagram of the low volume road life cycle.

This result has been achieved through discussing with senior Queensland Department of Main Roads officers the issues in low volume road development, considering other studies, and developing an initial understanding of the key objectives and the potential inputs. This latter process has been assisted through presentation, by the author, of the infrastructure life cycle modelling and analysis process at a technical workshop, and obtaining feedback from that workshop, plus the development of best practice guidelines, by the Queensland Department of Main Roads, for road construction in western areas. To date, 16 objectives and 40 inputs have been identified.

A case study approach is being used, the first road selected for this purpose being the section of the Kennedy Developmental Road between Winton and Hughenden, in central-northern Queensland. This road is being progressively sealed over a number of years, initially using conventional road construction techniques, and more recently with a thin sealed pavement process, which uses geotextile fabric seal technology, and a stabilised subgrade to overcome problems with expansive soils.

Stakeholder workshops are also being held to better evaluate the life cycle factors, and to assign risk to the inputs in terms of achieving the objectives. Final linkage of the factors in the development these roads, and analysis, which will include technical issues not available through the stakeholder workshops, will then be undertaken, with a view to developing the final framework. Studies regarding the condition of this road (for example, Ramanujam, 1999) assist with this process.

Further case studies are being selected for the development of the framework into a general low volume roads strategic and evaluation and analysis tool.

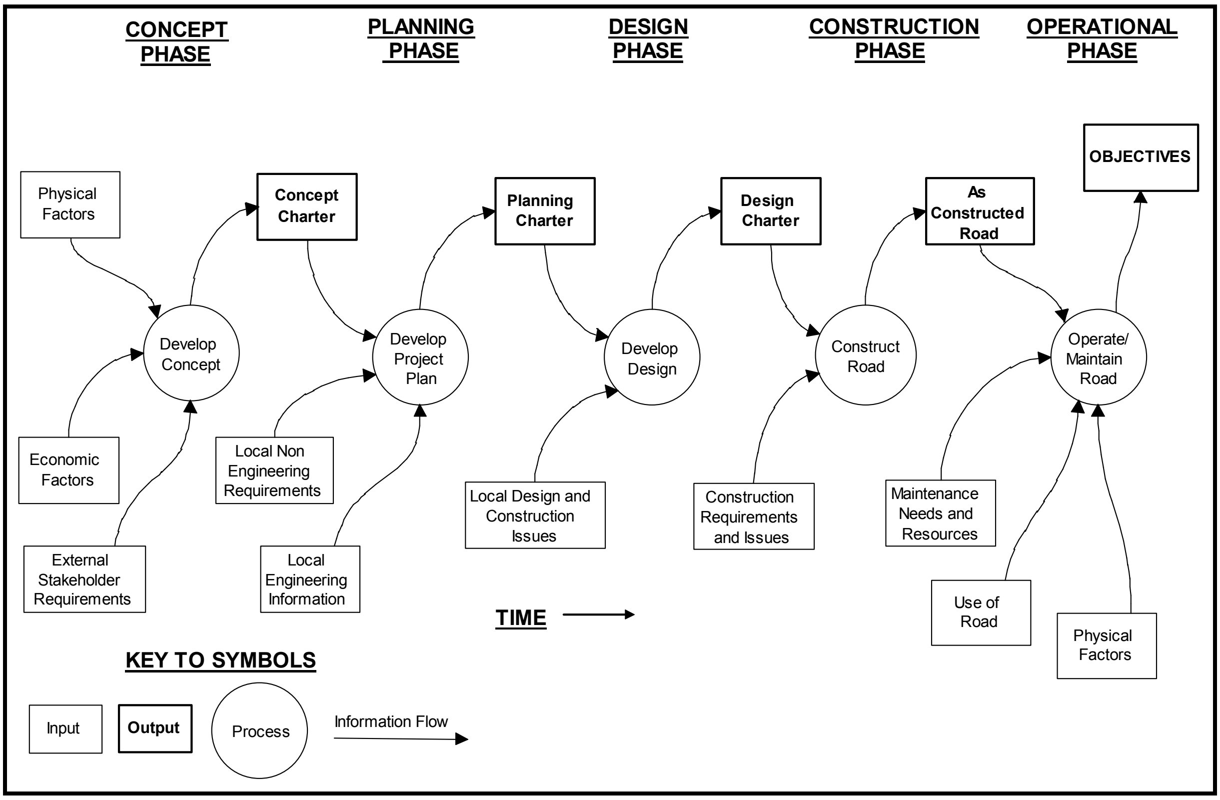

Figure 3 - Simplified View of Low Volume Road Life Cycle

DISCUSSION AND CONCLUSION

The methodology discussed in this paper is designed to provide the basis of a framework for analysing the infrastructure life cycle, with a view to identifying key factors in the development process, decision making, comparing options and highlighting further research.

By following a systematic process that uses flowcharting, structured analysis, and paired comparisons, the methodology provides understanding of linkages between the main factors in the infrastructure life cycle. A range of techniques enable analysis to be combined with judgment and experience in the sound understanding and evaluation of issues and their consequences in infrastructure development and management.

Through a case study approach, this methodology is now being applied to constructing a practical framework for the evaluation and analysis of alternative options for the development and management of low volume roads in remote areas of Australia.

REFERENCES

Grigg, Neil S. (1988), *Infrastructure Engineering and Management*, John Wiley and Sons, N.Y., USA.

Kepner, Charles H. and Tregoe, Benjamin B. (1965). *The Rational Manager - A Systematic Approach to Problem Solving and Decision Making*, McGraw-Hill, New York, USA.

Kepner, Charles H. and Tregoe, Benjamin B. (1981). *The New Rational Manager*, Kepner-Tregoe Inc, Princeton, New Jersey, USA.

Ramanujam, J. (1999), *Winton-Hughenden Road - Survey of Low Cost Fabric Seal Jobs*, Queensland Department of Main Roads.

Saaty, Thomas L. and Vargas, Luis G. (1982), *The Logic of Priorities - Applications in Business, Energy, Health, and Transportation,* Kluwer-Nijhoff Publishing, Boston, USA.

Thorpe, D. S. (1998), *A Process for the Management of Physical Infrastructure*, PhD Thesis, Queensland University of Technology.

Thorpe, D.S. (1999), *A Process for Modelling Infrastructure Development*, International Conference on Construction Process Re-engineering, Sydney, NSW.