SYSTEM DYNAMICS MODEL OF A STATE HIGHWAY MANAGEMENT SYSTEM

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Abstract

A System Dynamics Model of a State Highway Management System (HMS) is developed to serve as an instrument for guiding policy-making, planning, budgeting, and programming for the Virginia Department of Transportation (VDOT). The HMS consists of five subsystems and a Management Information System (MIS) to determine model parameter values. Results of the simulation runs can be obtained according to existing procedures and trends, impacts of alternative economic forecasts, budget sizes, budget allocations, programming allocations between construction and maintenance, and various allocations within maintenance.

1. Background

The recent biennial surface transportation conditions and performance study released by the U.S. Department of Transportation warns that in 20 years, if funding gaps are not narrowed for maintaining 3.9 million miles of public roads and bridges, the portion of highway pavement rated "poor" will rise to 50%, up from 15% in 1993, and 40% of the nation's bridges will be rated as "deficient", up from 28% in 1994. The study served as a wake-up call for many states, and the Virginia Department of Transportation (VDOT) responded by funding a research project, reported on in this paper, to develop a model of a Highway Management System (HMS) for the Commonwealth to serve as a instrument for guiding policy-making, planning, budgeting and programming of highway construction, operation, and maintenance budget allocations.

2. Organization of the Model

The HMS, organized as shown in Figure 1, consists of a Functional Subsystem, a Physical Subsystem, an Administration Subsystem, a Financial Subsystem, an Evaluation Subsystem, and a Management Information Subsystem. The Functional Subsystem is defined by the highway life-cycle from planning, design, construction to maintenance. The Physical Subsystem consists of the Pavement Management System (PMS) and the Bridge Management System (BMS). The Administration Subsystem consists of the highway categories---Interstate, Primary, Secondary, and Urban Highways. The Financial Subsystem includes the budget allocation and revenue generation processes that support the other subsystems. The Evaluation Subsystem determines user benefits, non-user benefits, environmental impact, and consumer satisfaction. The Management Information System defines data that should be routinely collected and processed into information so as to automatically update parameter values in the various subsystems of the HMS

The model includes more than 220 variables in the five subsystems. However, development of the model was initiated from the recognition of the causal relationship between basic elements in the subsystems of the HMS as shown in the simplified causal diagram in Figure 1. As shown in the diagram, the increase of the socio-economic factors affects travel demand and revenues positively.

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The increase of revenues leads to an increase of the available budget for highway management. The increased budget will improve the physical condition of the highway system, while the increase of travel demand and the maintenance and construction costs will affect it negatively. The increases of these costs also increases the life-cycle cost of the highway system. The Measures of Effectiveness (MOE) are affected positively by the improvement of the physical condition of highway system and negatively by the increase of life-cycle costs of the highway system. The improvement of the MOEs impact the socio-economic environment favorably, thus closing the loop.

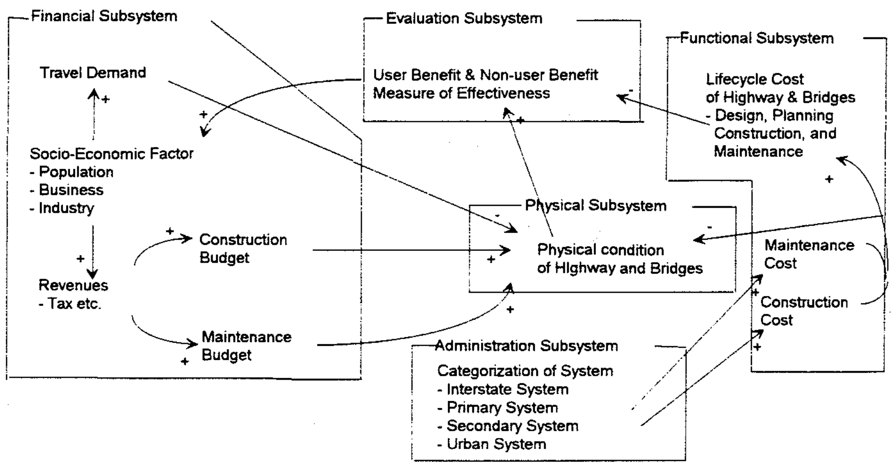

Figure 1. Simplified Causal Relationships Between HMS Subsystems

3. Description of The Subsystems

The Physical Subsystem consists of the Pavement Management System (PMS) and the Bridge Management System (BMS). The PMS includes the prediction of highway congestion and deterioration. The BMS, illustrated in Figure 2, shows the physical and functional conditions of the highway bridges. Both Physical Subsystems also provide quality indices for highways and bridges. The functional subsystem includes routines which estimate the Life-Cycle Cost (LCC) of the Commonwealth's highway network. The LCC is broken down to diverse maintenance cost structures for each physical and functional level of the bridges and highways.

The highway system can be categorized as Interstate Highways, Primary Highways, Secondary Highways and Urban Highways, each of which is planned, operated, and maintained by different standards, and different maintenance and construction costs. The Administration Subsystem produces the simulation results for the different categories of the highway system.

The Financial Subsystem includes routines concerning revenue generation, budget allocation, and the estimation of socio-economic inputs. Revenues come mainly from the Transportation Trust Fund and Highway Management and Operation Fund. Various allocation variables which can represent policy and programming alternatives are included in this subsystem (See Figure 3). The Evaluation Subsystem will function as an evaluation routine for the entire HMS system, and provides objective indices which help show the feasibility of the alternatives. The Evaluation Subsystem estimates user benefits, non-user benefits, and other MOEs such as Comprehensive Level of Service (CLOS), Net Present Value (NPV), and Benefit Cost Ratio (BCR).

Physical Subsystem: Bridge Management System (PHSS-BMS)

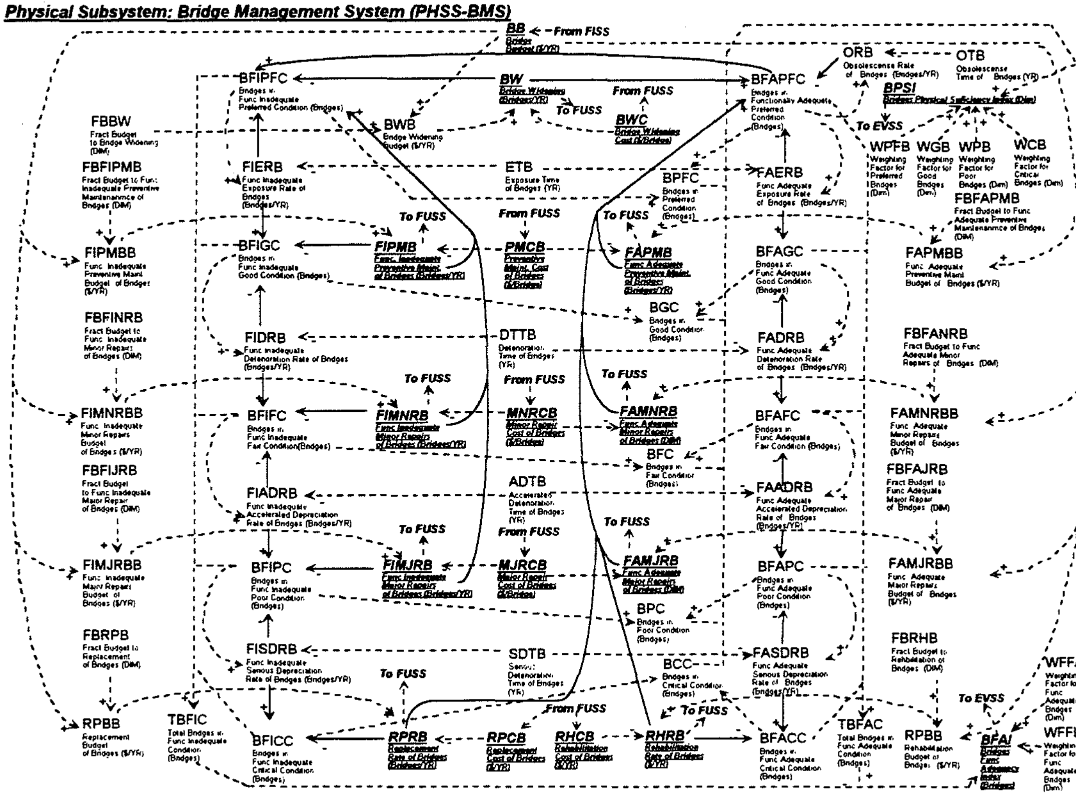

Figure 2. Bridge Management System

Financial Subsystem (FISS)

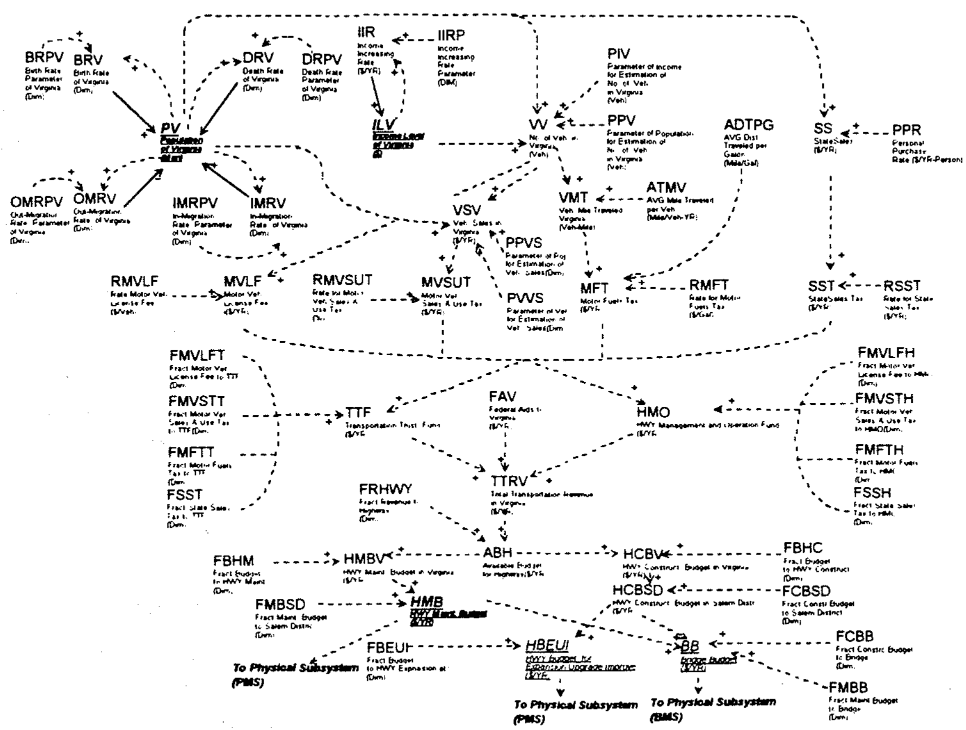

Figure 3. Financial Subsystem

4. Simulation Results

Simulation is performed with parameter values based on the available data from VDOT with best estimates used for unavailable data. The distribution of the budgets to each of the management activities is assumed for the basic run. Figure 4 illustrates the basic simulation results for the changes of the physical conditions of the highway and bridge systems for 20 years.

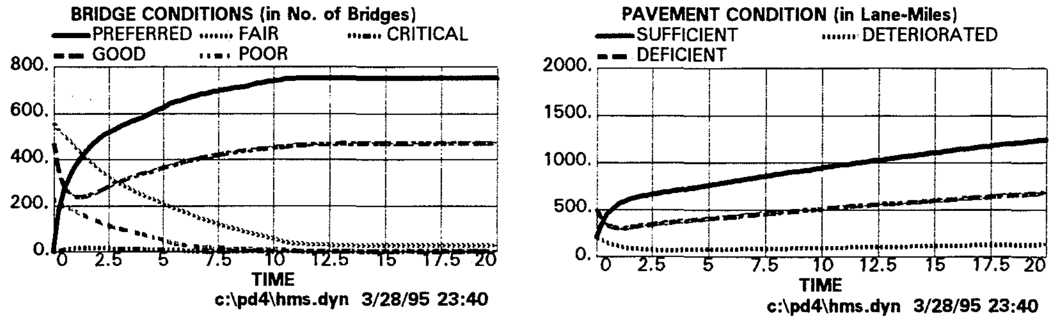

Figure 4. Basic Simulation Results

Several critical decisions must be made in highway management operations. For instance, how much money is needed for maintenance compared to construction is one of the most critical decisions. The next level in the decision-making hierarchy is how much money must go to bridge maintenance compared to highway pavement maintenance. Figure 5 illustrates an approach to optimization for this multiple decision variable problem with Fraction of Budget to Highway Maintenance (FBHM) and Fraction of Maintenance Budget to Bridge (FMBB).

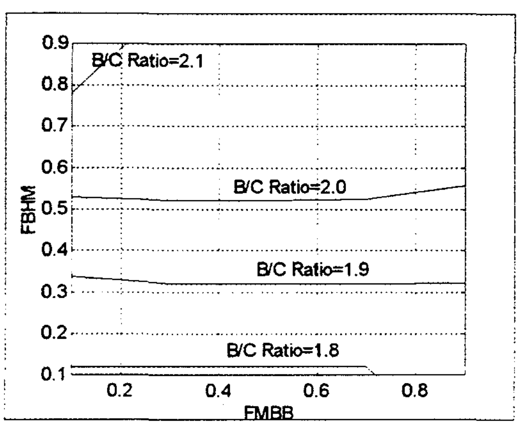

Figure 5. Results of Multi-Decision Variable Problem

As shown in the example above, the HMS model can provide solutions for network level highway management decisions according to policy, planning, and budgeting scenarios. Alternatives at the project level can also be evaluated in the HMS by testing the effect of changing the fraction of budget for each maintenance activity.

5. References

- Chasey, A.D., de la Garza, J.M., and Drew, D.R. (1995) "Simulation Model for Measuring the Impact of Deferred Maintenance"; Proceedings of the 1995 Simulation Multi Conference, The Society of Computer Simulation; Phoenix, AZ; April 9-13, 1995
- de la Garza, J. M., Chasey, A.D., and Drew, D.R. (1995), "The Impact of deferred Maintenance on the Subsystem"; Proposal to VDOT from Virginia Tech; May 15, 1995
- Huang, J.F., Moussavi, S.M., and Drew, D.R. (1983), "A Simulation Model for Managing State Highway Maintenance"; Winter Simulation Conference Proceedings" 1983 Vol. 1, IEEE, New York
- Kim, W. (1995), "System Dynamics Model of a Highway Management System for VDOT", Ph. D. Dissertation Proposal, Civil Engineering Department, Virginia Tech