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A network option portfolio management framework for adaptive transportation planning

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ABSTRACT

A real option portfolio management framework is proposed to make use of an adaptive network design problem developed using stochastic dynamic programming methodologies. The framework is extended from Smit's and Trigeorgis' option portfolio framework to incorporate network synergies. The adaptive planning framework is defined and tested on a case study with time series origin–destination demand data. Historically, OD time series data is costly to obtain, and there has not been much need for it because most transportation models use a single time-invariant estimate based on deterministic forecasting of demand. Despite the high cost and institutional barriers of obtaining abundant OD time series data, we illustrate how having higher fidelity data along with an adaptive planning framework can result in a number of improved management strategies. An insertion heuristic is adopted to run the lower bound adaptive network design problem for a coarse Iran network with 834 nodes, 1121 links, and 10 years of time series data for 71,795 OD pairs.

1. Background

Conventional practice in transportation planning relies on a passive approach to project investment. Each project is typically evaluated in a single long range future forecast year, and then compared against other projects on a year-to-year basis for funding without any adaptation to changing conditions over time. Although project investment decisions are made on a year-to-year basis with the long term plan in mind (Kim et al., 2008; Salling and Banister, 2009), there is a lack of a systematic framework to continually evaluate projects against each other under changing conditions. There is increasing interest from public sector agencies to adopt a more active management style of project management. In an ongoing National Cooperative Highway Research Program (NCHRP) study, Caplice and Dahlburg (2011) point to the flaws of forecasting with point estimates and suggest a qualitative scenario planning approach to identify long term possible future scenarios which can be monitored using news updates as "sensors in the ground". Nonetheless, recent surveys of public agencies continue to report an ongoing mismatch between the state of practice and the state of the art and the desire to address that gap (Hatzopoulou and Miller, 2009).

Given the gap, one might expect to find a robust academic literature devoted to time dependent transportation planning. Multi-period transportation network design was proposed as early as the 1970s (Steenbrink, 1974). However, a number of important advances in this field were only made in recent years due to modeling and computational complexities. Wei and Schonfeld (1993) and Kim et al. (2008) provide heuristics for solving multi-period discrete network design problems under a deterministic setting. Szeto and Lo published a number of papers in the area of deterministic multi-period continuous network design, the most recent of which include tolling (Szeto and Lo, 2008) and cost recovery (Lo and Szeto, 2009).

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However, practitioners' skepticism of state-of-the-art deterministic network design models (Hatzopoulou and Miller, 2009) call to question whether purely deterministic approaches are sufficient under a world of greater uncertainty. Sensitivity approaches have been developed to address this concern for deterministic single period model solutions (Salling and Banister, 2009) as well as for multi-period network design (Szeto and Lo, 2005). The conclusions of these studies indicate a greater need for more flexible, adaptive planning approaches.

A number of attempts at incorporating uncertainty in network design and investment models have been considered, although stochastic demand and capacity are generally dealt with using stationary, static distributions with scenario planning approaches. Stochastic programming efforts have been applied to bi-level network design problems where congestion effects occur (Waller and Ziliaskopoulos, 2001; Chen and Yang, 2004) as well as in facility location and inventory management problems (Shu et al., 2005; Snyder et al., 2007). These studies do not consider multi-period, time-dependent design decisions with stochastic variables.

Ukkusuri and Patil (2009) propose a multi-period stochastic network design problem formulation that accounts for elastic demand. They formulate the model of allocating design variables to a number of links as a mathematical program with equilibrium constraints (MPEC) with stochastic demand over multiple time periods. However, this formulation does not treat future period investment decisions as explicit options that depend on the realization of all the stochastic elements up to that point, as an adapted process.

A truly flexible planning approach requires consideration of multiple periods and adaptive decision-making which is essentially stochastic dynamic programming. Chow and Regan (2011b) propose a Link Investment Deferral Option Set (LIDOS) and a lower bound solution for this problem. LIDOS is a stochastic dynamic programming approach to network design, which is re-christened as an adaptive network design problem (ANDP) for simplicity. In the problem, each link investment is treated as a separate option whose investment could impact the value of other link investments. Details of the ANDP can be found in Chow and Regan (2011b). The current research serves as a companion piece; its contribution is the definition of a transportation planning framework that embodies the ANDP, using concepts from portfolio management that incorporates real option strategies. Both concepts of portfolio management and real options are defined in Section 2. The framework is empirically tested on a network where time series OD data is available so that illustrative comparisons of planning strategies can be made against more conventional and current state of the art practices.

2. Real option portfolio management

In the competitive private sector, many firms have adopted portfolio management methods to systematically manage sets of projects over time. Cooper et al. (1998) define portfolio management:

> "*Portfolio management is a dynamic decision process, whereby a business's list of active new product (and R&D) projects is constantly updated and revised. In this process, new projects are evaluated, selected, and prioritized; existing projects may be accelerated, killed, or de-prioritized; and resources are allocated and reallocated to the active projects. The portfolio decision process is characterized by uncertain and changing information, dynamic opportunities, multiple goals and strategic considerations, interdependence among projects, and multiple decision-makers and locations.*"

As portfolio management, transportation planning should involve a systematic balancing between short term profits (in terms of welfare benefits) and long term growth considerations. Risk should factor into the valuation of projects and overall strategic goals of the organization. To some degree, transportation planning already embodies elements of portfolio management. Short term project programming incorporates long range planning forecasts; multiple projects are deterministically compared against one another; and project objectives are related directly to long term social welfare or sustainability goals. However, there are still many gaps to be found: a lack of an adaptive mechanism in the planning process, which is largely due to lack of data collected for that purpose, and a lack of consideration for uncertainty. Anecdotal evidence indicates an emerging realization from practitioners to this effect. For example, Wells (2010) presents a portfolio management process adopted by the Federal Aviation Administration to centralize management of operations. Wiegmans (2010) and Olavson et al. (2010) apply portfolio management methods to freight and logistics for managing risk in supply chain networks. Both studies propose reducing risk by diversifying transport options into a portfolio of options. Neither one explicitly quantifies the value of adaptation within their portfolio.

Portfolio management that explicitly incorporates value from adaptation is demonstrated by Luehrman (1998) using real option theory. Real option theory is an investment evaluation method derived from corporate finance. The underlying concept is simply to enable continuous decision-making within some time horizon. By doing so, the decision can be adapted to the latest data to maximize its value. In option theory, this argument considers an investment as a right that can expire as opposed to a static obligation. Real option methods have been shown to be most effective in high capital cost industries with high profit volatility. Luehrman's real option portfolio management model can be illustrated with an option space shown in Fig. 1. A review of real option theory pertaining to transportation is provided in Chow and Regan (2011a).

Under this framework, the traditional discounted cash flow (DCF) method of evaluating projects is represented in the upper regions of "never" and "now". Portfolio management approaches that do not utilize real option theory would incorrectly quantify the value of all projects in the portfolio as static commitments. In reality, treating investments as options instead of commitments can expand the space into a number of other strategic considerations as shown in Fig. 1. Multiple