ROAD NETWORK PLANNING APPROACH FOR DEVELOPING COUNTRIES

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ABSTRACT

Investments in road network infrastructures are crucial for developing countries that are experiencing considerable economic growth. Given the social impacts and the massive financial outlays involving massive involved in these investment efforts, decisions need to be carefully planned. However, the long-term planning of these investments is always associated with large uncertainties. This paper presents an overview of a research project in progress aimed at developing a multi-period interurban road network planning optimization framework particularly designed for developing countries. In this framework, it is assumed that investment decision influence mobility over time; not only due to a potential increase on mobility demand but also cause by it changes mobility patterns. A system dynamics approach is used to capture these long-term mobility changes and the results are incorporated it in the optimization framework. Flexibility on the investments decisions is also considered, by adopting a real options valuation to analyze the reliability of the road investments over the multi-periods of analysis. Based on an existing optimization framework, a decision-support tool will be developed in order to support decision-makers in the road planning process.

Keywords: Multi-period optimization; Travel demand forecast; System dynamics; Flexibility

INTRODUCTION

Road investments have, in the short and long-term, impacts on the mobility, environment, territorial cohesion, and economies of the countries. This is particular evident in the case of major road network investments done in developing countries. The mobility paradigm can significantly change with the improvement of the main network of the country. Nevertheless, this paradigm shift is never taken into consideration in the planning decision process of these road investments. It is usually assumed that the future demand is given or is estimated based on the current mobility patterns, not considering, for instance, the change in the economics and demographic dynamics caused by the improvement of the road system.

In this paper we present a research project that aims at develop a multi-period optimization approach to the interurban road network planning problem in which the mobility changes are modeled as a function of the investments done in the previous periods. The approach is based on the previous work of the second author (Santos et al. 2009; Santos and Antunes 2012) and the research project constitutes the doctoral project of the first author.

The research will improve an existing multi-objective optimization model (presented in Santos et al. 2009) in three major aspects. The first one is the way future travel demand is estimated. Currently, the model assumes demand as elastic, directly influenced by the investment decisions. However, it does not consider that major network improvements change mobility patterns, caused by socioeconomic and territorial dynamics. We propose to address these relations in an innovative manner, by using system dynamics analysis. The second aspect to be improved is the definition of multi-period design plans. The existing model assumes a single period, considering a planning horizon of 15 or 20 years. However, decisions makers would rather prefer an investment plan divided in smaller time periods. Thus, a multi-period analysis is proposed in which the overall 15-20 years plan is divided in plans for 2 to 5 years periods, giving decision makers a sense of which links of the road network plan should be developed in each time period, according to the available budget at that time. A myopic analysis is proposed to do this dynamic planning. Finally, we propose to introduce the concept of investment flexibility in the optimization model in order to tackle the uncertainty inevitable associated with the forecasting of the long-term travel demand. Real-option analysis is proposed to incorporate flexibility in the planning decision process. This means that roads could be improved adopting a multi-stage investment scheme. For instance, for a particular road link, three options could be adopted: it could be improved in the first period from a slow two-lane highway directly to a six-lane motorway; it could be improved to a four-lane motorway, investing less money but taking the risk of not guaranteeing a minimum level of service if the future demand is higher than expected; or it could be improved in the first period to a four-lane motorway with the necessary characteristics to be improved again to a six-lane motorway in a future period.

The paper is divided in eight sections. After this introductory section, it is presented the context of road investments in the world and why this planning problem is on the political agenda of some countries. Then, it is defined the motivation and the problem to be addressed. In the fourth section is provided a general context of the research proposed, followed by its objectives. The methodology proposed and the major expected contributions are presented next. Final comments are provided in the last section of the paper.

ROAD INVESTMENT CONTEXT

Geographical space, or the way we perceive it, has changed over the years due to new economical perspectives. There has been a significant growth in the number of trips, and their dimensions. People no longer work and reside in the same areas. The distance between where we live and where we work has never been as large as it is now. International trade and travel has caused a surge in the necessity to provide new and improved responses to greater travel demands. With the increase of mobility needs, in terms of people and goods, transportation systems have had a crucial role in the well-being of human society.

The main factor for the continued growth in demand for transport has been the exponential growth in car use. What is now being observed in developing counties, such as Brazil, India and China, in terms of car use increase, was witnessed in developing countries during the second half of the 20th century. For instance, from 1960 to 2002 the amount of vehicles in countries belonging to the OECD increased from 115 million to 617 million with an annual average growth rate of 4.1% (Dargay et al. 2007). The United States (US) registered an increase in vehicles of 168 million, from 74 million to 242 million since 1960 (Office of Highway Policy Information 2010), while in countries belonging to western European Union (EU), the number of vehicles has tripled in the last 30 years, at an increase of 3 million vehicles each year (European Commission 2001).

China is an example of a developing nation that has recently made a great investment to improve its national road networks. In the 1990s, investment in infrastructure became a national priority and various policies were implemented to promote the rapid construction of highways. Chinese government, at all levels, has embarked on major highway investment programs. At the core of this program is the National Trunk Highway System (NTHS) to be completed by 2020. It consists of a 35,000 km network composed of 12 major highways with an estimated cost of 120€ billion, connecting all provincial capitals and cities with populations exceeding 500,000 inhabitants (100 major cities). All sections of the NTHS will match US Interstate or European motorway standards (Nogales 2004). The development of expressways has been particularly remarkable, with the total length increasing from 147 kilometers in 1988 to 25,130 kilometers in 2002, equivalent to an average annual growth rate of 44 percent (Fan and Chan-Kang 2005).

Brazil, a fine example of a developing nation that is experiencing rapid economic and social growth rates, contrarily to China, has not made significant investments in the last two decades. Nevertheless, President Dilma Rousseff recently announced in the summer of 2012, that the government has decided to invest 15.6€ billion during the next 25 years in the construction of new highway and motorway links, connecting all major Brazilian cities (Brasil 2012).

In 1998, the government of India implemented the "The National Highways Development Project", aimed to upgrade, rehabilitate and widen major highways in India to a higher standard. Until 2006, 54€ billion have been invested, and 50€ billion are still to be invested in 40,000 km of highways and 10,000km of motorways (Kerley et al. 2006).
As can be acknowledged, large investments continue to be made around the world, either in the construction, expansion or maintenance of road networks. Considering the high monetary values involved, it is important to carefully define what investments should be made, and at what period in time.

PROBLEM STATEMENT AND MOTIVATION

Road investments have, in the short and long-term, impacts on the mobility, safety, environment, territorial cohesion, economy, and on the general development of countries. The inclusion of these socioeconomic drivers in the decision process is essential to fully analyze the impacts of the investments to be made. Moreover, given the amount of budget usually involved in these investments, the goals for the road investment planning should be to get the best from these investments in terms of some of these drivers, or all if possible. In practice, some of these goals are indirectly considered, or are rarely considered in a comprehensive way. Besides that, it is not always easy to analyze and measure the impacts of a road investment. In some cases, it is not even clear if the impacts are positive, negative or null. For instance, in terms of economic development, most decision makers and general public believe that road infrastructure investments are an important mechanism to promote economic development and regional growth. However, when we analyze past investment based on empirical studies, the impact that road investments have on economic development and regional growth is difficult to determine. While there are authors that demonstrate there is a direct and positive relation between the two (Aschauer1989a, 1989b) others defend that the correlation does not exist or that it is unclear (Garcia-Mila et al. 1996, Pereira 2000, Mittnik and Neumann 2001, Ribeiro et al. 2010). As stated by Lakshmanan and Anderson (2007), the impact that investments in road infrastructure have on the economy depend on the context in which they are made. The economic stage of a country or region, in terms of growth, the existing road network and the timing of the investment, influence the impulse it will have in terms of productivity.
Among the developing countries in the world, it should be noticed that there are quite significant economical differences between them. Some countries are extremely poor, with no perspectives of experiencing considerable economic growth in the near future. Production and demand of goods are made at an isolated local level, with little or no trade with neighbor markets. What this represents in terms of road infrastructure is usually the inexistence of anything that resembles a basic road network. On the opposite side of this group, there are countries that for one reason or another begin to economically develop. This leads to greater market trade, and what was once an isolated local market economy, opens up geographically. What is observed is an increase in mobility in terms of people (labor) and goods. Countries in this situation usually present a basic road network. Travel between

different areas of the country is possible, but not in a manner that can be considered efficient.

In an analysis of transport infrastructure productivity in countries at different stages of development, Canning and Bennathan (2001) find that higher elasticities are more likely observed in middle-income countries, than in lower and higher-income countries, as can be seen in Figure 1. With a growing economy, the addition of a new route to a road network, or the upgrade of an existing one to a higher standard of service, will positively affect productivity, with the geographical expansion of markets.

It is difficult to accurately predict the benefits a new road investment will have in economic terms. This uncertainty leads to the large deviation between the observed and forecasted traffic demands in roads built in several countries, even during the first few years of operation. In most transport planning cases, a demand forecast is made for a horizon year (e.g., 20 years), and the project is designed based on that forecast causing even larger traffic estimations deviation.

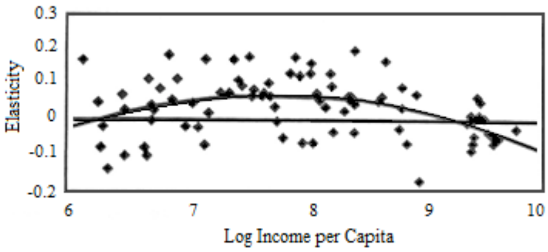

Figure 1: Elasticity of output with respect to paved roads (Canning and Bennathan 2001)

The motive behind this phenomenon is that the current road network planning process assumes that future demand is either exogenous to the network (i.e., independent of planning decisions) or endogenous but following the same mobility paradigm of the past. This proves to be a non-reasonable assumption, in particular for cases of major infrastructure investments in countries at a developing stage. For this reason, in developing countries and regions, when planning substantially new links, a new travel demand forecast approach should be adopted. Even though it is not easy to accurately assess its value, the incorporation of mobility changes in the long-term demand forecast can be a major challenge for future research.

RESEARCH CONTEXT

Despite the high complexity of considering a large number of objectives underlying road investment and increasing interest in studying its economic effects, in practice road network plans are typically developed following a trial-and-error approach (see Daly 2000). In this process, there is a set of predefined road investment schemes that are evaluated, compared and improved in a step-wise process. Each scheme is normally evaluated through cost-benefit analysis (CBA) and/or multi-criteria analysis (MCA) with the help of simulation models (see, e.g. Grant-Muller et al. 2001). In fact, in a study carried out by Guhnemann et al. (2012), an approach combining CBA and MCA within a road infrastructure development program was successfully used in supporting the effective implementation of transport policy when prioritizing projects previously defined. There are also a few cases of European countries, such as the Netherlands, Sweden and England, that developed simulation models to provide support in the CBA for their national road and transportation plans. The models are based on the classic four-step transportation model. The trial-and-error approach, even if based on a comprehensive set of predefined schemes, does not allow full exploration of possible planning solutions. This can only occur if optimization-based approaches are used.

The application of optimization techniques to the road investment planning is generally denominated as road network design problem (RNDP) in the literature. This problem has been subject of intense study and debate in the operation research field. The interest in this problem started in the 1970s with Leblanc (1975). Since then, several authors have proposed different methodologies and techniques for finding more efficient solutions. However, there is not, to the best of our knowledge, an application of these techniques in real world problems.

In his PhD thesis, Bruno Santos (Santos, 2009) proposed an inter-urban road network planning model which integrated efficiency, equity, robustness, and environmental objectives. The goal of this thesis was to address the RNDP in such a way that decision makers and practitioners would be more likely to use it for the long-term planning of road networks. The problem consisted of determining the best investment decisions to improve the quality of a national or regional road network assuming that decisions are necessarily made for a long time span – usually ten or more years.

The approach is based on a multi-objective optimization model, in which equity and robustness objectives are added to the efficiency objective dealt with in the vast majority of the RNDP literature. Decisions are taken according to a hierarchy of roads. That is, the RNDP formulation has a multi-level (discrete) nature, according to a set of road types. The traffic conditions of the network are assessed through the concept of level of service (LOS), which is a qualitative measure of the operational conditions of a traffic facility. This approach is compatible with the planning framework adopted in the Highway Capacity Manual - HCM (TRB 2000).

This said, in order to have an approach that can be used by decision makers in developing countries or regions, where there is a poor or a non-existent road network, there are still a few areas that can be developed to improve and adapt the proposed multi-objective optimization model.

Traffic demand forecast and system dynamics

Traffic demand forecasts are made mostly through the gravity model, as was done by Santos (2009). It is extremely complex to rigorously calculate this traffic demand considering all the factors that influence it (e.g., population growth, GDP growth, employment). The idea of this study is to try to assess its value through the consideration of some of these factors, in an innovative manner, through the use of system dynamics. This approach is believed to capture the real effect new links will have on the traffic demand of neighboring population, in particular in developing regions.

System dynamics, which is included in macro level simulation, was created in mid-1950s by Jay Forrester (Forrester, 1971). Hand simulations were the beginning of this field and only during the late 1950s and early 1960s the method evolves to the formal computer modeling stage (Forrester, 1961).

A system is a collection of parts interacting in such a way that the whole has properties that are not evident from each part considered individually (Coyle, 1996). Hence, the problems that result from the interaction of different parts of a system have to be analyzed instead of analyzing each isolated part individually. This methodology was developed exactly to do this, being its objective to describe, understand and model these complex systems whose behavior depends on time, that is, evolves with time, for instance the ones that deal with interactions between people and the environment, finding a way of managing them satisfactorily.

Originally system dynamics was used to understand industrial processes. However, currently it has been applied on policy analysis and design by private and public sectors (Radzicki and Taylor, 2008).

Transportation systems are complex, since they include several variables and nonlinear feedback loops. Hence, this methodology may be used to study them. One example where System Dynamics was applied to transportation systems was developed by Wang et al. (2008). In this work, the authors evaluated the performance of an urban transportation system regarding to different vehicle ownership policies and taking into consideration several factors, such as population, economic development, environment, travel demand, transport supply, and traffic congestion. Another example where this approach was applied was in Jordon's (2012) PhD thesis to forecast customer demand for electrical grid connections in developing nations. This is not related to transportation, but it is close to what is intended to develop in this work (forecasting demand for road networks).

Project scheduling

Another aspect of the optimization model is that it considers a single planning period, seeking for a solution for a given planning horizon. A road network project design is made considering a planning span that can range from 5 to 20 years, depending on the size of the project. This being, the intermediate configurations of the network are as important as the final plan in the horizon year. However, the traditional RNDP models originate solutions regarding the final shape of the road network at the planning horizon year, without offering any guidance about how to proceed during the planning time span. This is perhaps an important reason why planners are reluctant to apply a RNDP model to his/her practice,

There are a considerable amount of proposed models and approaches to project scheduling. Friesz et al. (1998) formulated a dynamic continuous disequilibrium network design model, which can find the optimal trajectories of the continuous link capacities over continuous time, as an optimal control problem model. Kydes (2002) then studied the model further and improved the solution algorithm. Lo and Szeto (2003) and Szeto and Lo (2005) also studied a dynamic version of continuous RNDP models. Kim et.al (2007) proposed a model similar to the one used in Lo and Szeto (2003), except that its goal was not to find the optimal link capacities, but rather to find, in a dynamic manner, the optimal decision on whether to build a link or not. In this regard, the model is multi-period and discrete. One merit of the proposed model is its capability to deal with the link addition scheduling problem explicitly. As a byproduct, the model produces the annual spending requirements, which facilitates a budgeting process. Jong and Wonkyu (2008) present a discrete network design model that provides the final shape of a transportation network and the sequence and schedule of link construction during the planning span as well. Ukkusuri and Patil (2009) developed a multi time period design approach considering both demand uncertainty and demand elasticity. This provides decision makers with the ability to decide what to do, considering smaller, more foreseeable time periods, instead of the large periods these kinds of transportation infrastructure plans are designed for.

Flexibility

By introducing the investment scheduling in the planning approach, a new feature is to be incorporated in the optimization: the consideration of flexibility. Flexibility of a system regards the ability of the system to adapt to external changes, while maintaining satisfactory system performance (Morlok and Chang 2004). Due to the demand forecast uncertainty in medium and long term, flexibility can give a more adjusted response to the demand evolution throughout the lifespan of the infrastructure.

With the large investments being made in road transportation networks, and the large time spans thought which capital is invested, flexibility begins to play an important role in making planning decisions.

An uncertain future provides a range of opportunities and risks. By introducing the notion of flexibility in the planning process, planners can deal best with these eventualities and maximize the expected value (de Neufville and Scholtes 2011). There is always a difficulty in knowing what to build and at what time. It is not possible to predict with certainty what will happen in the future. To achieve the best results we must be able to adapt to circumstances as they arise. In road network planning that requires predicting long-term necessities, and being able to adapt the plan to new state of affairs that may occur. In this manner, projects and plans should be elaborated in a way in which they can be modified easily to take advantage of new opportunities, or to mitigate adversities.

Flexibility of engineering systems is not entirely a new concept. For instance, in manufacturing engineering, different dimensions of flexibility are considered with respect to machine, operations, labor, product, market, etc. (Vokurka and O'Leary-Kelly, 2000).

Research on the importance of flexibility in transportation systems is relatively recent. The external changes, generally, are not controllable. For a transportation system, these include changes in demand caused by spatial traffic patterns, social-demographic changes, and changes in the price of resources such as fuel, or infrastructure loss and degradation,. The desired system performance depends on the planners and users, and can be defined using capacity, level of service, survivability, and profitability measures. A qualitative comparison of node, arc, and temporal flexibility of auto, road, railroad, air, and telecommunication networks is given in Feitelson and Salomon (2000). The study defines network flexibility as the ease with which a network can adjust to changing circumstances and demands, both in terms of infrastructure and operation. Their study focuses only on intrinsic flexibility from the planners' point of view, and the conclusions are not substantiated by numerical examples. Goetz and Szyliowicz (1997) discuss the weakness of current practice of planning with the specific reference to the case of the Denver International Airport, and emphasize the need for adopting flexible investment approaches. Ukkusuri and Patil (2009) presented an approach to model flexibility in the RNDP under demand stochasticity and elasticity, i.e. the demand is influenced by the change in travel cost. They enhanced the understanding of transportation network flexibility by proposing a taxonomy and defining multiple dimensions of flexibility. In this way, they demonstrated that the presence of uncertainty could be dealt efficiently by scheduling the investment over time. In their proposal, instead of a single time period network design plan, they sequenced network investments over time. With this approach, planners gain the flexibility to change, delay, or even abandon future investments if necessary. Other parameters such as capacity and travel cost were considered deterministic for simplicity.

Real option analysis

A method commonly used to take into account the notion of flexibility in the evaluation of projects is real options analysis, also termed real option valuation.
The term "real options" was coined by Myers (1977). It referred to the application of option pricing theory to the valuation of non-financial or "real" investments with learning and flexibility, such as multi-stage research and development, modular manufacturing plant expansion and the like.
Real options valuation applies option valuation techniques to capital budgeting decisions (Campbell 2002). A real option itself is the right — but not the obligation — to undertake certain business initiatives, such as deferring, abandoning, expanding, staging, or contracting a capital investment project. Real options analysis, as a discipline, extends from its application in corporate finance, to decision making under uncertainty in general, adapting the techniques developed for financial options to "real-life" decisions. The flexibility available to management – i.e. the actual real options – generically, will relate to project size and project timing.
Mehndiratta (2000) found that many of the current responses to risks in making decisions on transportation investments could usefully be explained and improved upon by the real-options approach. This may result in higher value investments to accomplish the stated investment goals, while avoiding serious mistakes in investing in projects that may fall far short of the investment goals.

There are several applications of real options analysis to transport infrastructures. The optimal timing of investments has been the subject of great interest in the context of corporate finance, being linked to the development of real options analysis. McDonald and Siegel (1986) produced the seminal work that provides the basis for several analyses of the optimal timing of investments. Bowe and Lee (2004) analyze the expansion and contraction options in a high speed train project using real data from a project located in Taiwan. Pimentel et al. (2008) study the optimal timing of an investment in high speed rail. Godinho and Dias (2010) develop a model for the analysis of the optimal timing of a road infrastructure construction, the Douro Interior expressway, located in northeastern Portugal. They conclude that the use of real options analysis in transport infrastructure planning proves to be an important tool in decision making. It not only helps support decisions in terms of building a project or not but it analyses the benefits of postponing a project, or an extension of it, to a better timing. This makes the difference in making an economically viable road infrastructure.

OBJECTIVES

The proposed study is a continuous contribution of the work carried out by Santos, focusing its application to developing countries with poor road networks. Its purpose is to help decision makers plan long-term road networks by combining two separate modeling approaches, system dynamics and optimization, to consider endogenous traffic demand in the network design. The aim will be to address the RNDP in an innovative way, by considering potential mobility pattern changes, investment scheduling and design flexibility.
In particular, the objectives for this work will be to:

- Develop a multi-period optimization framework in which road investments are defined in time-period base.
- Estimate mobility pattern changes as a function of investment decisions, through a system dynamics approach.
- Consider flexibility in investment decisions by studying the possibility of doing multi-stage investments in the same road network element.
- Adapt the optimization tool with geographic information systems that can support decision makers in road planning process, bringing more benefits to society.
- Enhance the calculation algorithm in order to tackle the enhancements proposed in this work.

METHODOLOGY

In this strategic planning problem, traffic demand needs to be simulated for a long period. The impact of road investment decision, throughout time, in travel demand, will be estimated with base on a gravity model. This model assumes that travel demand will vary according to some fix relations between demand and a set of socio-demographic variables (e.g., demography, GDP, motorization rate, employment) and travel costs (or times). This means that it assumes that mobility pattern will remain the same during the analysis period of the road investment plan. In this work, this demand model will be improved by adopting a system dynamics approach to capture the impacts that major road investments made on a poor road network may have on mobility patterns.

The Optimization Base Algorithm (OBM) will then generate a solution for the horizon year (e.g., 20 years) based on the traffic demand forecasts made previously. The plan will define the layout of the network for the horizon year according to the budgets for the several time-periods considered.

The scheduling model will then define the network layout for each period considered (e.g., 4 periods of 5 years). A first approach to this scheduling model could be to use a myopic algorithm that, given the available budget for each period, will choose the best network layout for that given period (Antunes and Peeters, 2001). The road level for each link in a given period will be defined based on the road level of the previous period (or the initial road level for the analysis of the first period) and on the road level of the final network, for the horizon year. Later in this research, this myopic approach could be improved to a "panoramic" (or sequential) optimization approach. In this type of algorithms the best solutions for each period are obtained in an integrated approach, by considering not the optimal for the specific period but the combination of optimums for all periods in the analysis. These algorithms are, however, more computationally demanding.

After having the scheduling model running, system dynamics can be used to create different demand scenarios - e.g., a high demand growth scenario; a base demand scenario; and a low demand growth scenario. With base on the results for each scenario, the flexibility model will compare the results obtained for the different scenarios and identify those roads that have different improvements under different scenarios. Those roads will be selected for a flexibility analysis. The flexibility analysis will consist on a real options analysis (de Neufville et al., 2009). The analysis will compare the option of improving the road according to the base demand scenario, and the option of improving the road according to the low demand growth scenario and make another improve at an intermediate period. The comparison can be done by computing the net present value (NPV) of each solution and the cost of LOS deficit (calculate, e.g., by multiplying the estimated total time lost associated to the demand of higher demand scenarios with the value of time and the probability of the scenario). The best option will be the one with the lower NPV and cost of LOS deficit.

This step of introducing flexibility will result in the analysis of the state, trying to minimize the general costs associated with the road network investments. The possible outcome will be a new budget scheme (redistributing the investments by periods) and a new final network layout. In order to respect the budget for each period, the investments to be made in each period should be re-planned.

The entire procedure is to be carried out on a GIS Platform, in a user-friendly manner, to support decision makers throughout the process.

The different stages of the research will be tested and analyzed with the application of the model to small size random road network case studies. This procedure is necessary to validate each one of the new features added to the modeling approach, and verify the accuracy of the conclusions reached in each case. One last case study, based on a real life situation, will be used once the goals of each stage are met, to validate the model as a whole, and to examine the obtained results for the region in question.

MAJOR EXPECTED CONTRIBUTIONS

There are three major contributions of the proposed thesis:

- The first is the consideration of system dynamics to predict possible mobility patterns changes as an effect of major road investments.

- The second major contribution is to create a multi-period optimization tool for road network planning, that decision makers and practitioners will be likely to use in the process of planning road networks.

- The third is the consideration of flexibility in a road network optimization problem.

To a lesser extent, this approach will also contribute to:

- The improvement and analysis of solution methods to solve the proposed model.

- The study of a real-life case study, validating the final model with all the proposed enhancements. This may attract the attention of decision makers and practitioners to use the proposed approach in their practice, trusting it to be a reliable tool.

CONCLUSION

This paper presents an overview of a research project aimed at developing a multi-period interurban road network planning optimization framework particular design for developing countries. The research will be based on a multi-objective optimization model developed by one of the authors in the past. The validity and capability of this model has been discussed in previous papers. The research discussed in this paper, in general terms, will consist on the improvement of this existing model in three major aspects: the incorporation of a system dynamic analysis to analyse the long-term impacts of road investments in the mobility patterns; the consideration of a dynamic (multi-period) investment planning; and the incorporation of the investment flexibility concept. The resulting modelling framework will consist in an innovative approach to the road network planning problem more suitable to be used by practitioners and decision makers in the solving real-world road investment problems, in particular for developing countries.

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