A SYSTEM DYNAMICS-BASED METHOD FOR DEMAND FORECASTING IN INFRASTRUCTURE PROJECTS - A CASE OF PPP PROJECTS

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Concession contracts are one of the most popular PPP arrangements. However, there are still a few problems regarding the successful implementation of such arrangements, such as estimating a realistic figure for the demand of services offered by the facility. Lake of demand, or demand variation, is a widespread practice when developing infrastructure projects. In the case of concessions, such practices are the origin of significant risk as the forecasted demand is a key variable in the financial and economic evaluation of any PPP project that needs to be accurately identified and then managed. Demand forecasting is a complex and dynamic process, as several inter-related qualitative and quantitative factors affect demand. This paper proposes a system dynamics-based method in which different factors affecting demand are considered and modelled holistically. The system dynamics concept has been employed to build up a set of cause-effect diagrams which will finally be incorporated to develop a conceptual demand model. This model establishes the causal structure of the demand system, which will help to portray and define the impacts of different factors on demand volume.

Keywords: cause-effect diagrams, concession, demand forecasting, system dynamics.

INTRODUCTION

Nations across the world have witnessed a major growth in the use of PPP over the last two decades. A study by McKinsey (2008) suggested that the private sector raised $105 billion to fund infrastructure facilities between 2006 and mid-2007. This growing trend of governments allocating major public investments for infrastructure projects to the private sector means, in many cases, that governments look to the private sector to finance projects using the projects' anticipated revenues as security rather than relying upon a direct sovereign guarantee for the projects. These kinds of PPP arrangements are broadly known as concession contracts. Concession contracts have widely been used to deliver economic infrastructure projects such as roads, water facilities and power stations (Zhang and Kumarswamy 2001). The World Bank

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reported that concession contracts accounted for about 50% of overall PPP contracts, making them the most popular type of PPP arrangements.

Despite the successful implementation of most concession contracts, in that they deliver the project on time and within the projected budget, financial difficulties faced during the operation stage have, in many cases, affected the success and overall project viability. The sluggish performance of many of these projects results in demand risk being of particular importance. Since the revenue for concession projects is basically based on service demand volume, any risk associated with demand in the operation stage will be translated into equivalent revenue risk, increasing the need to prioritise and address this type of risk appropriately when deciding, planning and operating these kinds of PPP projects.

The feasibility study of any infrastructure project entails forecasting the expected demand for the service provided by the facility in question. Several factors, both qualitative and quantitative in nature, need to be accounted for. In addition, many of these factors are inter-dependent, making demand forecasting a complex process. The conventional method employed for demand forecasting can be broadly classified into statistical and artificial intelligence methods. While most of the former cannot accommodate interrelations between factors, the artificial intelligence method can do this; however, the large amount of data required to model developments in the latter is still a concern.

Considering the deficiencies of traditional methods, the variety of factors and their complex interrelated structure, this paper proposes a system dynamics-based method to model such complexity. The SD method is well-known for its capacity to deal with the dynamic and complex nature of real systems. This research aims at developing a dynamic model to overcome the main deficiencies and drawbacks of the models in use. The dynamic model will help to derive elasticises of demand with respect to various potential influences. The proposed system dynamics-based forecasting model will advance the state of the practice and respond to the policy requirements of developing infrastructure projects.

The next section of this paper presents an overview of demand risk in infrastructure projects, followed by a literature review related to demand forecasting. System dynamics is then introduced as a potential tool for public service demand forecasting. Next, the proposed model for forecasting demand in PPP projects is introduced, and finally conclusions are derived.

DEMAND RISK IN INFRASTRUCTURE PROJECTS

Quiggin (2004) identified demand risk as "the possibility of unforeseen variation in the demand for services generated by a project." Variations in demand volume have been observed in many infrastructure projects. Bain (2002) explored 32 toll road projects all over the world, which included bridges, highways and tunnels. The study illustrated that the actual traffic volume for 28 of the projects was below what was projected. This core sample was extended to include 104 international PPP toll road projects in 2005, but the main results regarding the discrepancy between actual and forecasted traffic volume did not change. The range of actual/forecast ratios is from 86% below what was predicted to 51% above what was predicted (Bain 2009). Flyvbjerg *et al.* (2005) investigated 210 projects in 14 countries. The study showed that over 50% of transportation projects average a 20% discrepancy between actual and forecasted demand. In addition, the study suggested that this inaccuracy in demand forecasting is common across the different types of transportation infrastructures (highways, tunnels and bridges). Another study by Flyvbjeg (2007) indicated that the actual number of travellers on 22 urban rail projects around the world averaged 50.8% lower than predicted. The number of travellers for 75% of those projects was at least 40% lower than forecast, and only two schemes achieved the predicted demand. The work concluded that urban rail project projections are frequently far from actual demand. Moreover, a study by Engel *et al.* (2003) showed that inaccuracy regarding demand forecasting is common in highway projects in Latin America. Engel (2006) concluded that inaccuracy in demand forecasting was the major reason for transportation project distress in the United States.

DEMAND FORECASTING

The uncertainty inherent in demand volume in infrastructure projects necessitates employing more advanced methods to achieve realistic demand forecasting at the pre-project stage. This is particularly significant for concession contracts, where the demand-based financial performance is the main determinant of the project's success. The World Bank (2008) reported that unrealistic forecasts are a major reason for most toll road failures (cited in Li and Hensher 2010). In many infrastructure projects, the significance of undertaking the forecast process is underrated, and sometimes this is not even achieved. Trujillo *et al.* (2000) noted that while the employment of PPP to deliver infrastructure projects is increasing, there is growing evidence of a failure to appreciate demand forecasting in the formulation of partnership agreements. They added that it is not unusual for project partners to allocate larger proportions of the budget to construction studies than to demand estimations; this ratio averages 1:5.

Quinet (1998) categorised the sources of inaccuracy in demand forecasting as follows: inadequacy of the model structure, inaccuracy of the current data, and uncertainty in prediction of the future value of exogenous variables. In addition, a study by Flyvbjeg (2005) showed that there are two reasons for errors in traffic forecasting; namely technical mistakes in the methodology and the strategic behaviour of the bidders (optimism and bias). Moreover, Niles and Nelson (2001) identified uncertainty in model design and structure as one of the reasons for forecasting errors. They suggested improving the current models by integrating new variables, or introducing and designing new models for demand forecasting.

To overcome the optimism misrepresentation related to the strategic behaviour of the project stockholders, Flyvbjerg (2007) introduced a reference class forecasting method in order to build this optimism bias into the forecast. The main deficiency of this method is the large number of similar projects required to establish the probability distributions necessary to calculate the final forecasted figure. In addition, the similarity issue remains questionable, especially for those non- routine Greenfield projects where it is quite difficult to find two projects with similar attributes and built in a similar environment. Quinet (1998) argues that it is difficult to compare comparable things when topic is related to traffic, the conditions of implementing a particular project is different from that defined for any other. However, assuming the presence of optimism bias and that the forecasting figure should include it, based on the reference class forecasting method, the final figure is the initial figure forecasted by the model minus/plus a proportion of this initial figure in order to accounts for optimism bias. Given this, if the forecasting model produces initial figure which is unrealistic owing to any kind of deficiency in the model, the problem will be further exacerbated when calculating the optimism bias proportion based on this figure and then including them together. Moreover, this problem will extend to other projects as this figure will be used as a reference to any potential future project. Therefore, to help the planners to include the right percentile of this bias in their models and to develop a reliable class of references for future use, it is necessary for their model to produce realistic initial figures. Given this and that several scholars attribute the variation in demand to reasons pertinent to the forecasting models themselves, the authors argue that the reasons related to model structure and design need first to be accounted for.

Forrester (1968) suggested that simple solutions to problems could have undesirable results, and more sophisticated levels of analysis could provide better solutions. It was observed that, for simplicity, many forecasting models identify only some of the influencing factors and assume that these could account for all the outcomes. Although quantitative and qualitative factors play an approximately equivalent role in shaping the demand behaviour for services provided by PPP infrastructure projects, most of the forecasting tools have mainly focused on quantitative factors, which often have external effects on demand. However, the worst situations occur when both these factors are totally ignored and the demand for the services provided by a facility is estimated based on the available statistical data of similar facilities (Ng *et al.* 2007). Moreover, these factors affecting demand in PPP projects typically have complex interrelations that need to be taken into consideration when developing the forecasting model. These factors dynamically interact, leading to constant changes in the system. Niles and Nelson (2001) mentioned that although the mobility and dynamism of the urban system is noticeable, decision-makers still utilise closed, static models to produce demand projections for transportation projects, which constitutes a major weakness in the modelling of demand forecasting. Subsequently, the method used for forecasting in many infrastructure projects could be highly misleading, and the inaccurate forecasting outputs could lead to business failure.

Owing to the particular nature of the factors affecting demand in PPP projects, this research is devoted to developing an enhanced demand forecasting approach which takes into consideration the factors and relationships among them, and provides a more realistic and reliable estimation. The modelling technique adopted is system dynamics, which is a powerful method that is designed to analyse complex systems by including all the relevant factors and their relationships. The following section briefly introduces the concept of system dynamics.

SYSTEM DYNAMICS

With the aim of improving the decision-making process, system dynamics (SD) was developed by Jay Forrester at Massachusetts Institute of Technology in the 1950s. SD is a method of representing complex and dynamic systems with the aid of computer simulation software. It is an experimental approach to system thinking (Sterman 2000), and a way to include all relevant factors, cause-effect relationships, time delay and feedback loops which factor in the unexpected behaviour of the complex system. The SD method has been successfully applied in different fields, including economics, ecology, health science, physics, mathematics and biology.

SD is an appropriate technique with which to study problems of a complex and time dependent nature. It is one of the most suitable approaches for dealing with causal structures governing the behaviour of complex systems. Demand forecasting is complex, integrating several inter-correlated factors whose behaviours are time-dependent. For instance, the change in the local economy at present may have impacts on demand in the future. System dynamics has the ability to simulate this change over time, along with the effect it has on the dependent factors and the system in general. This method has the capacity to take into consideration different quantitative and qualitative factors in order to capture the dynamic interactions between these factors.

PROPOSED MODEL

The SD modelling process includes two main phases: Qualitative System Dynamics, or model conceptualisation, and Quantitative System Dynamics. While the former is mainly based on creating cause-effect diagrams, which is the main purpose of this paper, the latter is devoted to quantitative computer simulations.

Cause-effect or causal diagrams are a visual representation of the interactions and feedback loops between different factors affecting demand. These cause-effect diagrams, representing the hypothesis of the model, depict how each factor can affect the outcome, either directly or through other intermediate factors, as well as the effect that one variable has on the others. They clearly show the direction and the kind of causality among different variables (Love *et al.* 1999). A relationship between two variables (x1) and (x2) is represented by an arrow. For each relationship, the link between the two variables is noted as positive if the increase in the variable at the tail of the arrow (x1) would cause an increase to the variable at the head (x2). The relationship is noted as negative if increase in (x1) would cause a decrease in (x2). One significant aspect of the SD causal diagram is the feedback loop, which can be positive or negative. While variables in positive or reinforcing loops (R) increase or decrease indefinitely, variables in negative or balancing loops (B) stabilise over time.

The main factors affecting demand in PPP projects have previously been identified by authors (Alasad *et al.* 2011). With reference to the outcomes of this previous work, a conceptual demand forecasting model, which describes the relationships between different factors, is proposed (Figure 1). The demand forecast model consists of many cause-effect diagrams with several reinforcing and balancing loops. However, due to space limitations, the generic structure of the conceptual demand forecasting model as well as socio-economic and fee level cause-effect diagrams will be presented in this paper.

THE CONCEPTUAL DEMAND FORECASTING MODEL

The conceptual model for demand forecasting - Figure (1) - suggests that the level of demand for services provided by PPP facilities is jointly affected by several qualitative and quantitative factors. These factors include public acceptance, willingness to pay, fee level, socio-economic growth in the facility area, competition from existing facilities and availability of supportive facilities. The model depicts how these factors affect one-other and how they eventually affect demand.

The next two sections present cause-effect diagrams for two of these factors; namely the fee level and socio-economic factors.

Socio-economic cause-effect diagram

The socio-economic context in which the facility is operated has an impact on the level of demand, and subsequently on the future revenues of the facility. Infrastructure projects are known to be a generator of economic activities. In addition, the facility users play a significant role in shifting economic resources into the facility area, leading to substantial economic growth.

Introducing a new infrastructure project can have local and systematic impacts. While systematic impacts can influence all potential users of the facility, local impacts specifically affect those people in the immediate vicinity (Kanaroglou *et al.* 1998). In the local impact context, introducing an infrastructure facility to a specific region is likely to bring significant benefits. It can augment employment opportunities and enhance the productivity of the area due to enabling additional economic activities (agriculture, manufacturing, construction), which can trigger a significant increase in employment and income. This will finally result in a positive impact on the local economy in general.

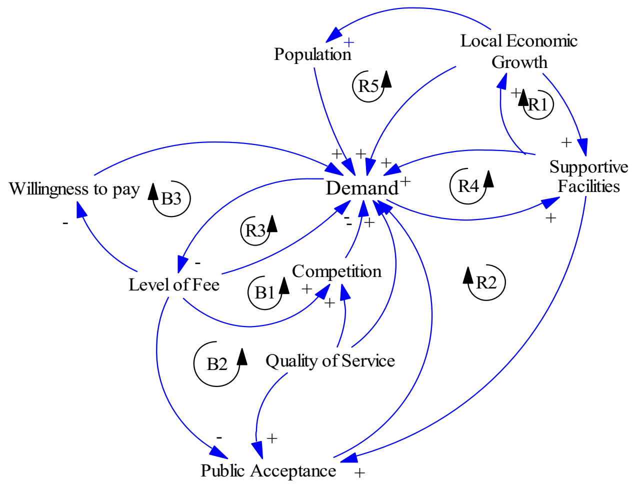

Fig.1: Conceptual Demand Forecasting Model

For instance, constructing a new highway will lead to many fuel and service stations, firms, retail stores, warehouses and restaurants being established along the highway and in the proximity of the facility. For example, it was declared that the realisation of the second Peace Bridge between Canada and USA facilitated $29 billion in trade and contributed to the construction of an international trade complex in the adjoining area. Similar situations were identified in the UK for the Humber Bridge and other projects (McQuaid and Greig 2002).

On the other hand, this growth in the local economy resulting from the introduction of a new infrastructure project is likely to cause changes in the local demographic over a period of time. This change in population number and distribution over the course of a few years can create tremendous changes in demand. When the population of the areas surrounding a facility grows, this is likely to be reflected in the growth of facility usage demand. The cause-effect diagram of socio-economic factors illustrates the impact of this change in the socio-economic context of the facility area on the level of demand.

The economic growth cause-effect diagram suggests many feedback loops, as shown in Figure 2. The first is a reinforcing loop, R1 (economic growth-labour supply-demand-alternative facilities-economic growth), where the economic growth in the facility area will trigger more job opportunities, attracting more labour to the area, which will consequently increase the level of demand. However, a continuous increase in demand resulting from more job opportunities and other factors will create the need for another facility to relieve inordinate pressure on the original one. This new project will eventually contribute to economic growth. However, it should be noted that the construction of another facility in the area will most likely negatively affect the demand for the service provided by the facility in question (B1 loop). The second reinforcing loop, R2, suggests that the economic growth will enhance migration to the facility area, increasing the area's population and ultimately resulting in demand growth. The R3 loop suggests that economic growth will help increase the level of income, leading to a further increase in the purchasing power of potential users, and eventually having a positive impact on the level of demand. R4 is the final reinforcing loop, where the new constructed facility (alternative facility) will help attract more migrants to the facility area, causing population growth and consequently increasing the total demand.

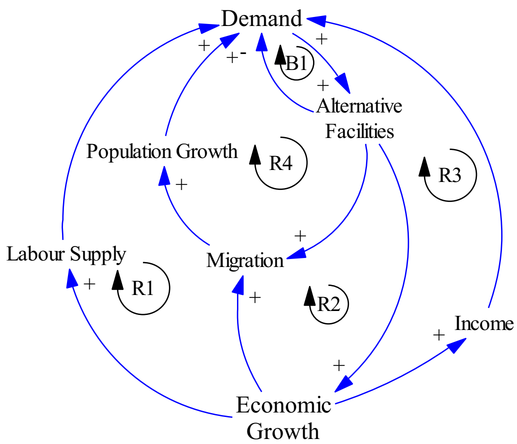

Fig.2: Socio-economic cause-effect diagram

Level of fee cause-effect diagram

For concession contracts to be financially viable, the total revenue collected from users over the concession period should cover the project cost plus expected profit. The project cost typically includes construction cost, operation and maintenance costs and cost of capital, including the interest on loans and dividends on equity raised to finance the project by the private company.

A study by Zhang (2005) showed that an appropriate toll/tariff level and suitable adjustment formula are the most significant factors for success within the critical sound financial package PPP success factor. The employment of PPP to deliver infrastructure projects requires an understanding of the trade-off between the financial and economic viability of the facility in question. In many cases, the expensive construction programme and the willingness of the private sector to fasten repayment of the debt service and achieve high profits leads to the levying of high tariffs. This high level of fee is likely to have a negative impact on the demand for services offered by the facility. In Sydney Airport railway link (in Australia), for instance, the high ticket price was the main reason for the low patronage observed. The ticket cost for using the railway was roughly three times more expensive than other lines (Zou *et al.* 2008). Furthermore, in the case of toll roads, a high-level toll will definitely cause traffic to divert to any available alternative route, leaving the facility in question under-used. However, while the private sector is worrying about its profit and risk, the major concern of the user is the service price and quality, which can seriously affect the demand (Trujillo *et al.* 2000). Therefore, the fee level imposed for using the facility should strike a balance between achieving a reasonable return for the concessionaire and being compatible with the quality of service provided (Zhang and Kumaraswamy 2001). The level of fee cause-effect diagram illustrates how the change in fee level can influence the demand volume.

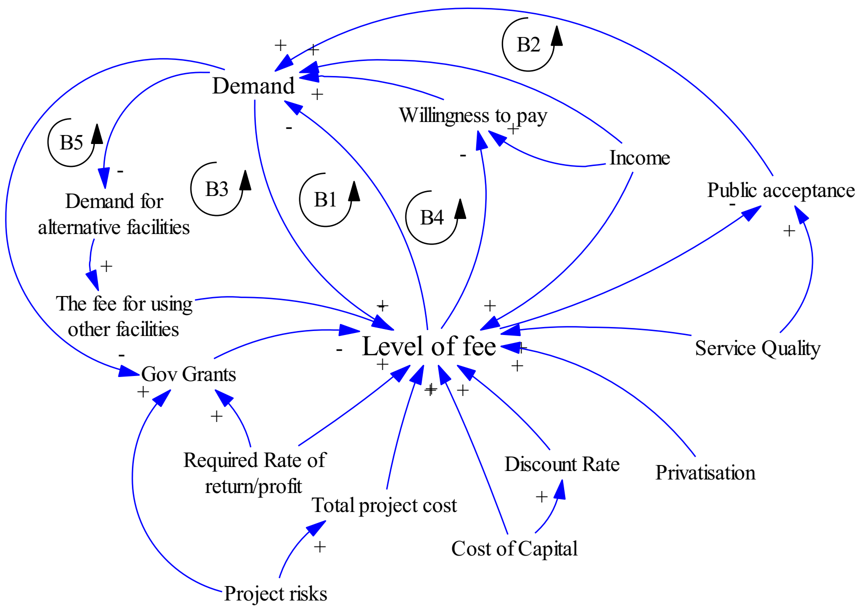

Fig. 3: Level of Fee Cause-effect diagram

The level of fee cause-effect diagram shows several balancing loops. The first balancing loop, B1, indicates that any increase in the level of fee will be directly translated into a decrease in the level of demand. However, a demand decline will most likely lead the operator to increase the fee for using the facility, causing further declines in the demand volume. The B2 balancing loop shows that when the level of fee increases, the public acceptance decreases, which will cause a further decrease in demand. This slackening of demand will lead the concessionaire to increase the fee for using the facility, and the loop starts again. As for the B3 balancing loop, any increase in the demand for the facility in question will be translated as a decrease in the demand for any other available alternative facility. The decline in demand for the alternative facility will lead the operator of this facility to increase the fee to compensate. This behaviour of the alternative facility operator will motivate the operator of the original facility to increase the fee as well, which will finally cause demand diversion to the alternative facility.

The B4 balancing loop suggests that the increase in the level of fee will lead to a decrease in willingness to pay, which, in turn, will lead to a decrease in the level of demand, causing the operator to further increase the fee level to compensate for the shortage in facility revenues. Based on the contract arrangements, the government is likely to provide grants to the private sector to ensure a reasonable user fee level. These kinds of grants will lead to a decrease in the level of fee for using the facility, causing a subsequent increase in demand. This increase in demand helps to decrease the amount of any further payment required by the government, as suggested by the B5 balancing loop.

As shown in Figure 3, several constant factors also affect the level of fee, such as the quality of service, cost of capital, discount rate, project cost and expected rate of return.

Finally, it should be mentioned that these cause-effect diagrams are barely developed, based on the literature review. Therefore, they need to be verified by a panel of experts and professionals in the demand forecasting and PPP fields, in order to produce validated cause-effect diagrams. The validated diagrams will be incorporated to form the final conceptual demand forecasting model.

CONCLUSIONS

Concessions, which are one principle of PPP, have been established by the government to pay for the construction of infrastructure projects and to make provision for the maintenance and operational costs. In addition to recouping its capital investment from the project revenue, the concessionaire is obliged to bear demand risk, which increases the significance of demand forecasting in these kinds of projects. Although many forecasting models have already been proposed, they remain primitive, and need major improvements in order to reliably forecast demand. These methods have some major weaknesses, including the huge amounts of data required, the fact that relationships between certain factors are ignored, and their static nature and simplicity. This paper has proposed a method to overcome these weaknesses. The system dynamics approach was employed to model and analyse the complex relationships among different factors affecting demand over time. The demand forecasting conceptual model portrays the interactions among different factors affecting demand, and defines how they do so. The cause-effect diagram of each factor, in turn, depicts the lower level interactions. The cause-effect diagrams will be verified by a panel of experts, and incorporated to produce the final conceptual model, which will then form the basis for the quantitative demand forecasting SD-based model. The expected model should help improve the practice of demand forecasting.

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