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Demand scenario analysis and planned capacity expansion: A system dynamics framework

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A B S T R A C T

This paper establishes an approach to develop models for forecasting demand and evaluating policy scenarios related to planned capacity expansion for meeting optimistic and pessimistic future demand projections. A system dynamics framework is used to model and to generate scenarios because of their capability of representing physical and information flows, which will enable us to understand the nonlinear dynamics behavior in uncertain conditions. These models can provide important inputs such as construction growth, GDP growth, and investment growth to specific business decisions such as planned capacity expansion policies that will improve the system performance.

1. Introduction

Analyzing demand is an integral part of manufacturing strategy that reflects the capacity utilization, which will be considered for making business decisions. Regarding to the growth of demand, it is important to evaluate and to forecast the volume of demand in the future based upon some scenarios analysis. In this study, we utilized cement as an example product, where it has short production cycles and is produced in big batches. In the case of batch production, stocks can occur and whether they do depend upon the policy of the firm [13]. Although such analysis may differ from one product to another, we keep the proposed model as generic as possible to facilitate its implementation on a wide spectrum of real-world cases. It can be easily verified that this model can be applied in other commodities such as infrastructure construction and cement raw materials.

In line with the economic growth, characterized by indices such as gross domestic product (GDP), investment and construction industry will grow. Cement is one of the key inputs in infrastructure development and hence its consumption is closely related to economic growth [5]. Growth in the construction industry has a direct relation with the demand of cement. The growth of GDP, investment, and construction will increase cement demand as well. The demand of this commodity varies regionally, seasonally, and secularly. The cement industry has often struggled to have the right amount of capacity in the right places and at right time [16].

Evolving trends in demand generate schedules for capacity expansion, specifying the size, location, and timing of these expansions in order to maximize the expected profit to the company. Demand forecast can be used as the input to planned capacity expansion for meeting the growing demand. In this research, we developed a model to analyze and to forecast the future demand based upon some demand scenarios. We classified the scenario models into two types: structure scenarios

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and parameter scenarios. Structure scenarios are scenarios that are generated by adding some feedback loops, adding new parameters, or by changing the structure of the feedback loops. Through this scenario, we analyzed the demand and the existing capacity to check whether the existing capacity can meet the future demand. We further divided the structure scenario into two scenarios – those without capacity expansion and those with capacity expansion – for analysis.

Parameter scenarios are scenarios that are generated by changing the values of the parameters. In these scenarios, we modify the values of GDP growth, investment growth, and construction growth based on the optimistic and the pessimistic projections. With the optimistic projection, we assumed that GDP, investment, and construction are predicted to grow in line with the economic growth. While in the pessimistic projection, we assumed that GDP, investment, and construction are projected to grow by a smaller percentage to the optimistic case.

When the demand for the commodity is difficult to forecast, system dynamics is the most effective approach because of several reasons [15]:

(1) Forecasts coming from calibrated system dynamics models are likely to be better and more informative than those from other approaches. The models are calibrated to historical data, and used to produce a forecast of the future demand. With the detailed and calibrated models, we will be able to accurately predict the demand volume based on demand scenario analysis. As a result, firms can avoid unnecessary capacity expansion because from the model output, it gives clear information on when the firm should expand the existing capacity to meet the future demand. Having a detailed, calibrated model that produces accurate forecasts results in better decisions and significant savings to the firm.
(2) System dynamics models can provide more reliable forecasts of short- to mid-term trends than statistical models, and therefore lead to better decisions.
(3) System dynamics models provide a means to determine key sensitivities, and therefore more robust sensitivities and scenarios.

This paper is organized as follows. Section 2 provides the literature review. Section 3 describes the base model development. Model validation is explained in Section 4. Section 5 demonstrates scenario development by modifying the information structure and parameter values to design capacity expansion policies. Finally in Section 6, conclusion, the important aspects of the system dynamics framework and the successfulness of the models are presented.

2. Literature review

The cement industry is of significance to the national economy as it supplies an essential product to the construction and civil engineering sectors. Therefore the cement industry is also sensitive to demand fluctuations of the housing sector. These fluctuations are caused in part by the effect of changes in interest rates for new construction activities, and variation in government spending on highways and buildings [28]. It is necessary for companies to have strategies and tactics to deal with such variations by, e.g., carrying inventory, maintaining the ability to flex capacity, and managing demand [19].

In order to maintain a specified service level at all times, the firm must keep up with the growth in demand. Therefore, the firm needs to expand its capacity as the demand grows. The analysis of the capacity expansion problem consists of two steps: first, determining the capacity required to provide a specified level of service, and second, deciding when to add capacity in order to maintain the same service level as the demand grows. The size of an expansion is based upon the forecast demand within the planning horizon. Booth and Vertinsky [3] have developed a strategic capacity expansion model for a newsprint firm. According to their research, long lead times and the enormous capital commitments increase the risks of firm failure when capacity is added prematurely. On the other hand, the risks of not adding capacity when additions are required involve probable losses of market share and the loss of opportunities to benefit from economies of scale to maintain the competitive advantage of the firm.

System dynamics models allow managers to test alternative assumptions, decisions and policies [6]. If more rapid industrial expansion is desired, managers may change assumptions regarding to production lag times or capacity expansion times to test the impact of alternative policy options. Wile and Smilonich [26] have utilized system dynamics to develop models to improve resources management policies. They identified some insights of policies during model building and testing, including group model testing, strategy, and scenario building.

Helo [14] has developed system dynamics models to obtain effects and capacity limitation in supply chains. He analyzed three simulation models, the demand magnification effect in supply chain, capacity surge effects and the trade-off between capacity utilization and lead times. According to his research, capacity utilization has an unambiguous connection to production costs, lead time and the capability to respond to the changes.

Orcun et al. [18] have utilized system dynamics simulations to compare capacity models for production planning. They examined the behavior of different models of manufacturing capacity in the face of different demand patterns to illustrate the assumptions about system behavior that are implicit in the different capacity models and to link the system dynamics terminologies to those used in the production planning community.

System dynamics was developed in 1950 by Jay W. Forrester of Massachusetts Institute of Technology (MIT). This framework is focused on system thinking, but takes additional steps of constructing and testing of a simulation model. System