Simulation Modelling Practice and Theory 18 (2010) 732–751

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

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

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ARTICLE INFO

Article history:
Received 16 January 2009
Received in revised form 17 January 2010
Accepted 20 January 2010
Available online 28 January 2010

Keywords:
Demand forecasting
System dynamics
Simulation
Capacity expansion

ABSTRACT

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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1569-190X/$ - see front matter
doi:10.1016/j.simpat.2010.01.013

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 dynamics simulation is performed to learn about the dynamics of the system behavior that may impact the planning solution by using closed-loop feedback and to design policies to improve system performance. It treats the interactions among the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy [9].The main characteristics of this method are the existence of complex systems, the change of system behavior, and the existence of the closed-loop feedback to describe the new information about the system conditions that will yield the next decision. Sterman [24] has developed steps to create system dynamics models as depicted in Fig. 1.

Step 1: Problem articulation: in this step, we need to find the real problem, identify the key variables and concepts, determine the time horizon and characterize the problem dynamically for understanding and designing policies to solve it.
Step 2: Dynamic hypothesis: modelers should develop a theory of how the problem arose. In this step, we need to develop a causal loop diagram that explains causal links among variables and convert the causal loop diagram into the flow diagram, which consists of three variables as depicted in Table 1.
Step 3: Formulation: to define system dynamics models, after we convert the causal loop diagram into the flow diagram, we should translate the system description into levels, rates and auxiliary equations. We need to estimate some parameters, behavioral relationships, and initial conditions. Writing equations will reveal gaps and inconsistencies that must be remedied in the prior description.
Step 4: Testing: the purpose of testing is to compare the simulated behavior of the model to the actual behavior of the system.
Step 5: Policy formulation and evaluation: once modelers have developed confidence in the structure and model behavior, we can utilize the valid model to design and evaluate policies for improvement. The interactions of different policies must also be considered, because the real systems are highly nonlinear and the impact of combination policies is usually not the sum of their impacts alone.

Duffie and Falu [8] have developed a dynamic model for closed-loop production planning and control (PPC) was proposed to control work in process (WIP) and capacity using control theoretic approaches. They investigated the effect of choosing different capacity scaling controller gains as well as the WIP controller gains on system performance and how this can be used to achieve required system responses.

Goncalves et al. [12] highlighted the issue of capacity variation in their push pull manufacturing SD model through the effect of capacity utilization on the production start rate. They showed how the sales and production effects interact to destabilize the system and degrade its performance. Vlachos et al. [25] proposed a model to study the long-term behavior of reverse supply chains applied it to re-manufacturing. For that purpose, they examined efficient re-manufacturing and collection capacity expansion policies that maintain profit while considering direct and indirect factors.

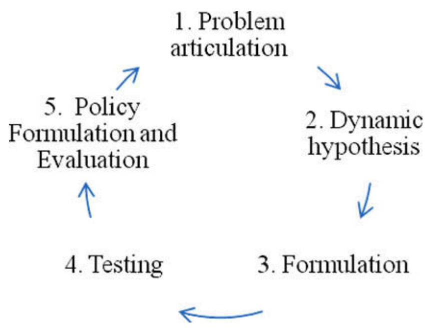

Fig. 1. System dynamics modeling process.

Table 1
Some variables in system dynamics.

Variable	Symbol	Description
Level		A quantity that accumulates over time, changing its value by accumulating or integrating rates
Rate		Change the values of levels
Auxiliary		Arise when the formulation of a level's influence on a rate involves one or more intermediate calculations, often useful in formulating complex rate equations, used for ease of communication and clarity

Yuan and Ashayeri [29] have analyzed capacity expansion decision in supply chains to identify the main (and mostly inter-dependent) factors affecting such a decision. They combine system dynamics loops and control theory simulations to study and analyze the impacts of various factors on capacity expansion strategies within a supply chain through some simulation experiments. The study shows that financial reporting delays can distract capacity expansion decisions, which signifies that they are as important as delivery lead time and can position a supply chain in distress by creating huge backlogs.

Deif and ElMaraghy [7] have developed SD model to analyze the operational complexity of dynamic capacity in multi-stage production. The model was demonstrated using an industrial case study of a multi-stage engine block production line. The analysis of simulation experiments results showed that ignoring complexity sources can lead to wrong decisions concerning both capacity scaling levels and backlog management scenarios.

The previous dynamic approaches to model and analyze the dynamic capacity planning problem focused on either controlling the capacity by considering some internal factors or exploring different policies to hedge against some disturbances. Although they offered good solutions for such problems, no research has studied the impact of macroeconomic conditions (external uncertainty inputs) such as, GDP growth and investment growth to the demand growth. Thus the research presented in this paper is motivated by the need to understand the effect of these uncertainties (based on optimistic and pessimistic projections) to the demand forecasting. It is believed that such understanding would result in reducing the complexity of the demand forecasting and the dynamic capacity planning management.

In general our research has focused on planned capacity expansion by developing models to forecast the future demand based on optimistic and pessimistic projections. These models have provided an understanding of complexity of the nonlinear dynamic behavior. We demonstrated a framework on how to develop a calibrated model by considering all uncertainties that come from internal and external factors. To encourage the exploration of some alternatives that might happen in the future and to provide a better reliable forecast we develop structure and parameter scenarios that will guide other researchers and firm's management in developing demand forecasting and planned capacity expansion.

System dynamics can be and has been applied to a wide range of problem domains such as strategy and corporate planning, public management and policy, business process development, biological and medical modeling, energy and the environment, theory development in the natural and social sciences, dynamic decision making, complex nonlinear dynamics, software engineering, and supply chain management.

3. Base model development

System dynamics has three important roles in developing a model. The first and the most important one is the system structure that will characterize its behavior. The second one is the nature of the structure where the mental models play an important role in the dynamic behavior of the system. The third one is that significant changes can be used to alter the structure (structure scenario). This structure can be represented by feedback loops.

Fig. 2 represents the causal loop diagram of demand scenario analysis and planned capacity expansion. Certain factors can affect the growth of the demand on a commodity such as cement, with construction growth as the internal factor and other factors such as GDP growth and investment growth as two external factors. The causal loop diagram has been used to describe basic causal mechanisms hypothesized to underlie the reference mode of behavior over time [21,24], to create a connection between structures and decisions that generate system behavior.

In general, this causal loop diagram consists of three main loops: order, inventory, and planned capacity. Order will determine the amount of production and will lead to national demand. Construction, GDP, and investment growths have positive effect on national demand. Increasing volume of national demand will increase the order volume and the other way around. A firm's market share plays an important role in determining the amount of order. The growth of national demand will lead

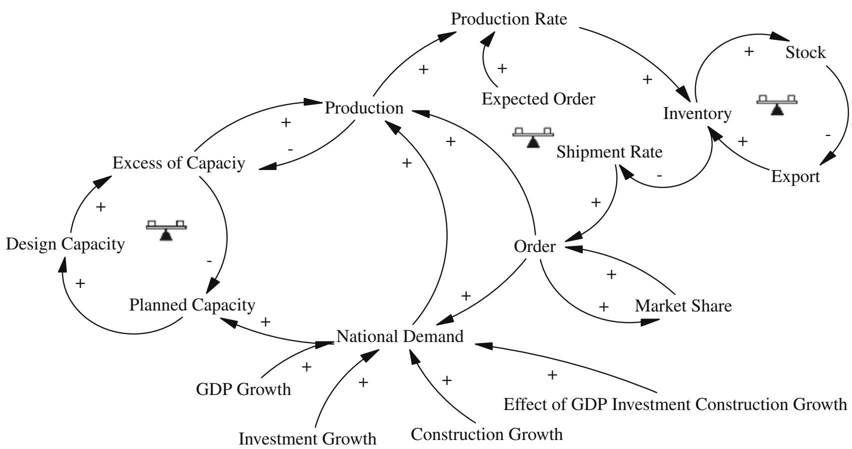

Fig. 2. Causal loop diagram of demand scenario analysis and planned capacity expansion.

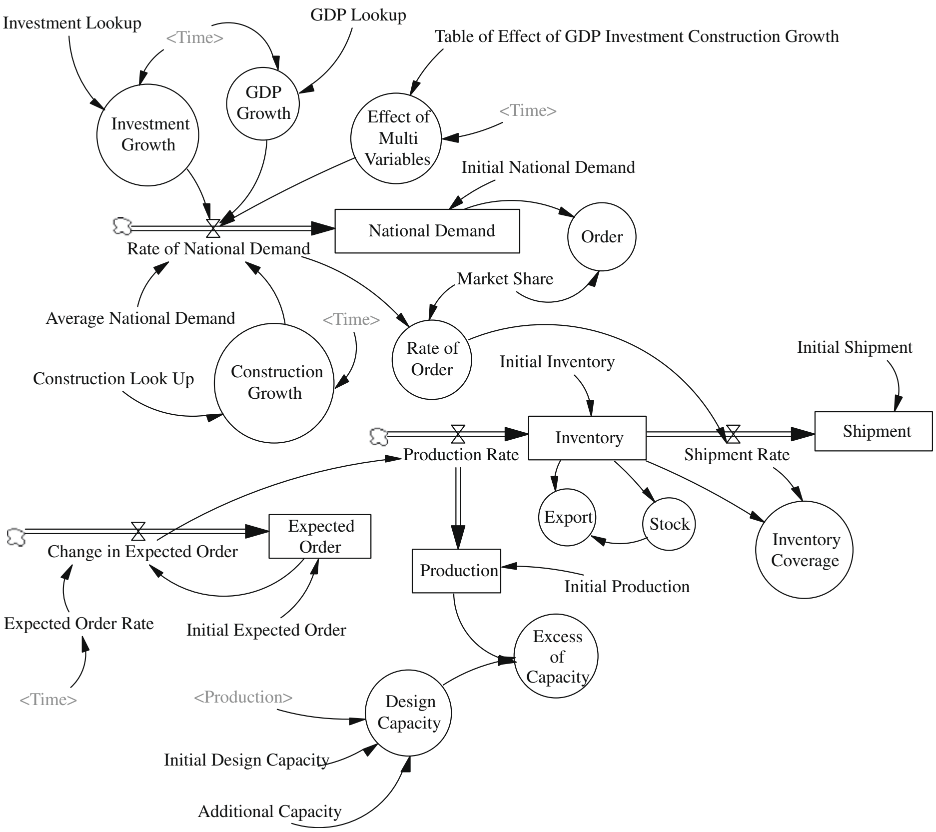

Fig. 3. Flow diagram of demand, production, and excess capacity.

to the elevation of the capacity utilization level. Therefore, planned capacity is required to meet the future demand. Additional capacity expansion will increase the design capacity that will generate excess capacity in the beginning. However, excess capacity will decrease in line with the demand growth.

Inventory is the discrepancy between production rate and shipment rate. As we can see from Fig. 2, firms separated stock from inventory based upon consideration that this commodity is easily bulky, only 10% of inventory be considered as stock to cover the demand fluctuation. The rest of the inventory will be exported to other countries. Export is restricted by the amount of inventory and stock. Fig. 3 shows the flow diagram of demand, production, and excess capacity (base model). This model consists of four sub-models: order, production, inventory, and excess capacity.

3.1. Order sub-model

The national cement consumption is determined by three factors: construction growth, GDP growth, and investment growth. Average national demand is a constant variable that we utilized in the model to generate the average rate of national demand. We classified national demand as a level variable to accumulate the rate of national demand. The rate of national demand will change the accumulation of national demand through entry of the basic unit represented in the national demand (see Eqs. (1) and (2)). Parameter dt represents the time interval of simulation. In this study, we set the time interval equal to one year and the time horizon to 15 years for the base model based upon consideration that during the period, the system behavior can be learned. Firm order is restricted by the market share that represents the firm's sales volume in the market (see Eq. (3)).

$$\text{National Demand}(t) = \text{National Demand}(t - \mathrm{d}t) + (\text{Rate of National Demand}) * \mathrm{d}t \tag{1}$$

$$\text{Rate of National Demand} = (\text{Average National Demand} * \text{Construction Growth}/100 * \text{GDP Growth}/100 * \text{Investment Growth}/100) * \text{Effect of Multi-Variables} \tag{2}$$

$$\text{Order} = \text{Market Share} * \text{National Demand} \tag{3}$$

Effect of Multi Variables is a table variable affected by GDP growth, construction growth, and investment growth. We consider *Effect of Multi Variables* to accommodate the nonlinear relationships among *Rate of National Demand, GDP Growth, Investment*

Growth, *Construction Growth*, and *Average National Demand*. The values of table variable affected by GDP growth, construction growth, and investment growth are calculated as follows (see Eq. (4)):

$$\text{Table variable affected by the growths of GDP\_Construction\_Investment} \\ = (\text{National Demand}(t+1) - \text{National Demand}(t))/\text{Rate of National Demand}(t) \quad (4)$$

In this study, we utilized Lookup or Table functions for *GDP Growth, Investment Growth, Construction Growth*, and *Effect of Multi Variables* based on consideration that their relationships are nonlinear. Lookup table represents the dynamic behavior of a physical system by mapping multiple inputs to a single output in a multidimensional data array. The general format of Lookup table can be described as follows:

$$\text{Table for effect of } X \text{ on } Y = (X_1, Y_1), (X_2, Y_2), \ldots, (X_n, Y_n)$$

where (X_i, Y_i) represents each pair of points defining the relationship. We set X_i as the time and Y_i as a variable that we want to utilize for the functions of *GDP Growth*, *Investment Growth*, *Construction Growth*, and *Effect of Multi Variables*. Each element of a matrix is a numerical quantity, which can be precisely located in terms of two indexing variables (see Eqs. (5)–(12)).

$$\text{GDP Lookup}([(1994,-20)-(2008,10)],(1994,7.3),(1995,7.5),(1996,8),(1997,4.7),(1998,-13),(1999,2), \\ (2000,5),(2001,5),(2002,4),(2003,4.5),(2004,5),(2005,5),(2006,6),(2007,5),(2008,6)) \quad (5)$$

$$\text{GDP Growth} = \text{GDP Lookup(Time)} \quad (6)$$

$$\text{Investment Lookup}([(1994,-40)-(2008,20)],(1994,28.3),(1995,30.3),(1996,31.3),(1997,8),(1998,-33), \\ (1999,-18),(2000,15),(2001,15),(2002,7),(2003,8),(2004,2.5),(2005,15.5),(2006,13),(2007,12),(2008,15)) \quad (7)$$

$$\text{Investment Growth} = \text{Investment Lookup(Time)} \quad (8)$$

$$\text{Construction Look Up}([(1994,0)-(2008,10)],(1994,12.3),(1995,12.5),(1996,12.9),(1997,8),(1998,-36), \\ (1999,-3),(2000,6),(2001,6),(2002,4),(2003,3),(2004,6.5),(2005,8),(2006,7.5),(2007,9),(2008,10)) \quad (9)$$

$$\text{Construction Growth} = \text{Construction Look Up(Time)} \quad (10)$$

$$\text{Table of Effect of GDP Investment Construction Growth}([(1994,0)-(2008,10)],(1994,14.31),(1995,13.6), \\ (1996,10.54),(1997,-760.66),(1998,-1.26),(1999,2473),(2000,120.66),(2001,122.52),(2002,470), \\ (2003,516),(2004,700),(2005,15),(2006,113.5),(2007,130),(2008,100)) \quad (11)$$

$$\text{Effect of Multi Variables} = \text{Table of Effect of GDP Investment Construction Growth(Time)} \quad (12)$$

3.2. Production sub-model

The amount of *Production* is made based on expected future order, where *Production* is defined as a level variable as it accumulates the *Production Rate* (see Eqs. (13) and (14)). *Production Rate* is restricted by *Change in Expected Order*, which means that the total production depends on the *Expected Order Rate* (demand forecasting). *Change in Expected Order* will be accumulated in *Expected Order* as a level variable that can accumulate the changes in the unit of simulation time (see Eqs. (15)–(17)). During the periods of 1994–1997 and 1999–2008, we set order grew around 6% annually and −1% in 1998 based on economic condition and management policy. We faced monetary crisis in 1998, and therefore the order growth was predicted to decline by 1%

$$\text{Production}(t) = \text{Production}(t-\mathrm{d}t) + (\text{Production Rate})^{*}\mathrm{d}t \quad (13)$$

$$\text{Production Rate} = \text{Change in Expected Order} \quad (14)$$

$$\text{Change in Expected Order} = \text{Expected Order}^{*}\text{Expected Order Rate} \quad (15)$$

$$\text{Expected Order}(t) = \text{Expected Order}(t-\mathrm{d}t) + (\text{Change in Expected Order})^{*}\mathrm{d}t \quad (16)$$

$$\text{Expected Order Rate} = \text{IF THEN ELSE(Time} = 1998, -0.01, 0.06) \quad (17)$$

3.3. Inventory sub-model

We defined *Inventory* as a level variable to accumulate the difference between *Production Rate* and *Shipment Rate* (see Eqs. (18)–(20)). Stock was set to be around 10% of *Inventory* based on management policy; the rest of the inventory will be exported to other countries. The amount of *Export* is restricted by *Inventory* and *Stock* (see Eqs. (21) and (22)).

Table 2
Values of parameters of the base model.

Parameter	Value	Unit
Average national demand	30,000,000	Tonnes
Initial expected order	4,000,000	Tonnes
Initial national demand	18,180,000	Tonnes
Initial production	4,100,000	Tonnes
Initial design capacity	4,100,000	Tonnes

$$\text{Inventory}(t) = \text{Inventory}(t - \mathrm{d}t) + (\text{Production Rate—Shipment Rate})^{*}\mathrm{d}t \tag{18}$$

$$\text{Shipment Rate} = \text{Rate of Order} \tag{19}$$

$$\text{Rate of Order} = \text{Market Share}^{*}\text{Rate of National Demand} \tag{20}$$

$$\text{Stock} = 0.1^{*}\text{Inventory} \tag{21}$$

$$\text{Export} = \text{Inventory} - \text{Stock} \tag{22}$$

3.4. Excess of capacity sub-model

We set *Excess of Capacity* as an auxiliary variable to carry out the functional equation. *Excess of Capacity* will be positive as long as the *Design Capacity* is greater than *Production*; otherwise, shortage capacity will occur if order from domestic market is greater than design capacity (see Eq. (23)).

In line with the domestic consumption (order) growth, the firm focuses on capacity expansion to meet rising demand and ensure uninterrupted supply in domestic market by providing the additional capacity since *Production* is greater than *Initial Design Capacity* (see Eq. (24)).

$$\text{Excess of Capacity} = \text{Design Capacity} - \text{Production} \tag{23}$$

$$\begin{aligned}\text{Design Capacity} = \text{IF THEN ELSE}(&\text{Production} > \text{Initial Design Capacity},\ \text{Initial Design Capacity}\\ &+ \text{Additional Capacity},\ \text{Initial Design Capacity})\end{aligned} \tag{24}$$

3.5. Parameter estimation

Parameter estimation is the process of utilizing data or observation from a system to develop mathematical models. The assumed model consists of a finite set of parameters, the values of which are calculated using estimation techniques. Parameter values can be drawn from all available sources, not merely from statistical analysis of time series. All information is admissible in the modeling process. The estimation of parameters can be obtained in some ways, e.g., statistics data, published reports, and statistical methods. In this research, we have already obtained data from PT. Semen Gresik, Indonesia's largest cement maker.

The coefficient estimation results for the *Expected Order Rate* and *Market Share* are given in Eqs. (25)–(27). Other values of coefficients of the base model are listed in Table 2

$$\text{Expected Order Rate}_{(1994-1997\ \text{and}\ 1999-2008)} = 6/100 \tag{25}$$

$$\text{Expected Order Rate}_{(1998)} = -1/100 \tag{26}$$

$$\text{Market share} = 0.22 \tag{27}$$

4. Model validation

Giannanasi et al. [11] have defined validation as the process of determining the simulation model based on an acceptably accurate representation of reality. The objective is to achieve a deeper understanding of the model. Validation deals with the assessment of the comparison between 'sufficiently accurate' computational results from the simulation and the actual/hypothetical data from the system [17]. There are three steps in determining if a simulation is an accurate representation of the actual system considered, namely, verification, validation and credibility [10]:

(a) Conceptual model validation is the process of determining whether the theories and assumptions underlying the conceptual model are correct and reasonable for the intended purpose of the model.
(b) Computerized model verification is the process of determining whether the model implementation accurately represents the developer's conceptual description of the model and the solution to the model [1].
(c) Credibility or operational validation is defined as determining whether the behavior of the model output has sufficient accuracy for the model's intended purpose over the domain of the model's intended applicability [23].

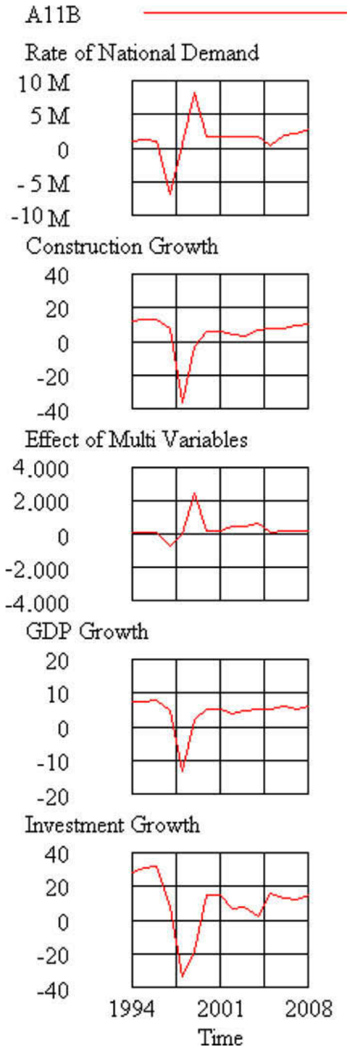

Fig. 4. Causal relationship of rate of national demand.

4.1. Base model run results

Base model run results are required to learn about the system behavior during the time horizon of simulation. In this research, we set the time horizon for the base model to 15 years, starting from 1994 to 2008. This time span will provide a better understanding of the system behavior of national consumption demand before and after we faced monetary crisis in 1998, which will have an impact on the outputs and the policy alternatives to be developed.

Fig. 4 demonstrates that *Rate of National Demand* in Indonesia during 1994–2008 was clearly impacted by construction growth, GDP growth, investment growth, and the effect of multi-variables (the growths of construction, GDP, and investment). As we can see from Fig. 4, GDP growth in Indonesia during 1994–2008 was between −13% and 7.5%. Investment growth rates were around −33% to 5% and construction industry grew around −36% to 12%. These negative growth rates were happened in 1998, when we faced monetary crisis that had negative impact on the demand of this commodity. All of these growths are given to the model as lookup tables. We demonstrated all these growths in the causal relationship graphs to analyze the relationships among *Rate of National Demand*, *Effect of Multi Variables*, *Construction Growth*, *GDP Growth*, and *Investment Growth* graphically. *Investment Growth* led to *Construction Growth* especially during 2005–2006.

We utilized *Effect of Multi Variables* to accommodate the nonlinear relationships among GDP growth, construction growth, and investment growth by using a lookup table function. This function represents the dynamic behavior of a physical system that represents the pairs of points, each of which defines the relationship such as depicted in Eq. (11). As a result of financial and monetary reforms implemented after the crisis and in line with economic growth, GDP and investment also grew, leading to a rise in demand for construction.

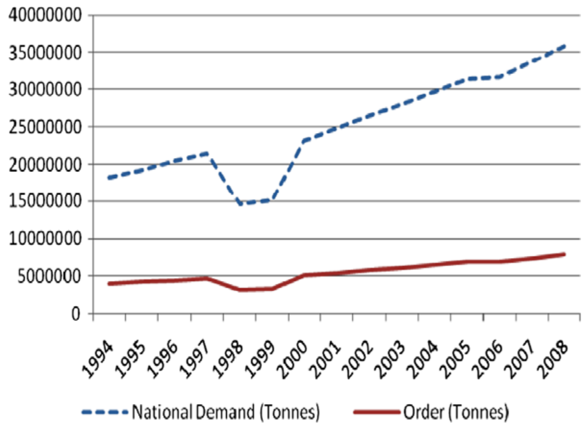

Fig. 5. National demand and order.

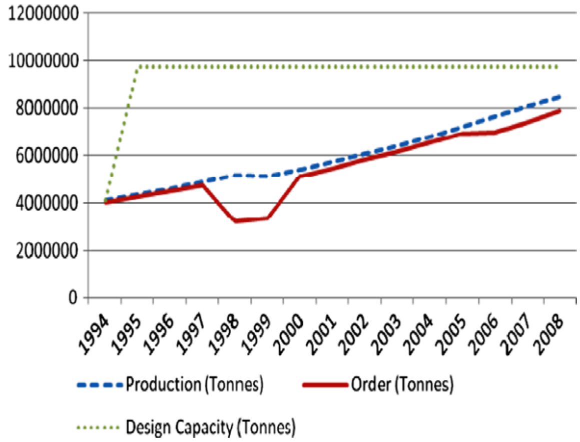

Fig. 6. Production, order, and design capacity.

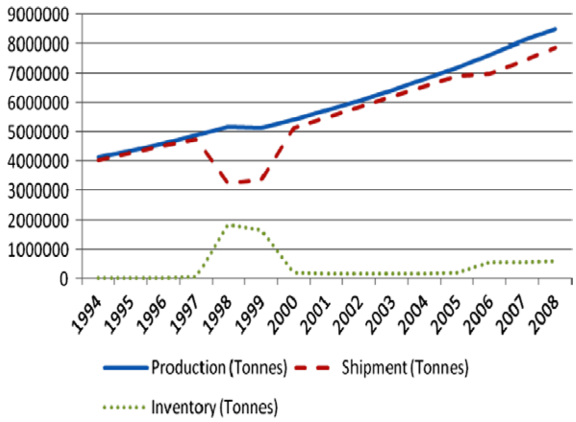

Fig. 7. Production, shipment, and inventory.

Fig. 5 represents the national demand and order during 1994–2008. As we can see from Fig. 5, national demand grew between −32% and 6.3%, in line with the economic condition during the period. In normal condition (before and after monetary crisis), the average growth rate of national demand was ±6% per year. Firm order depended on its market share. It was around 22% of national demand. *Order* grew around −32% to 7%, in line with national demand growth. *Order* achieved 7.8 million tons in 2008.

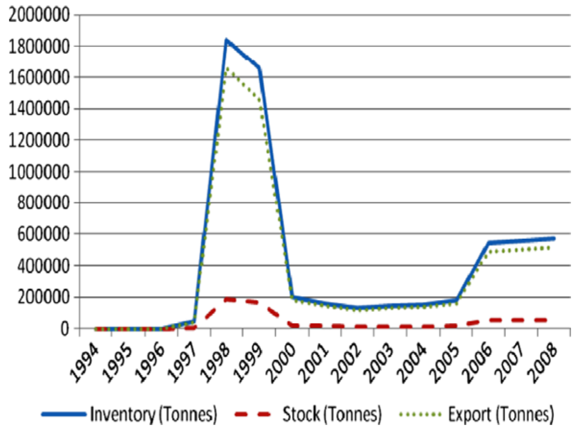

Fig. 8. Inventory, stock, and export.

Table 3
The average value of the simulation results ($\bar{S}$) and data ($\bar{A}$).

Variable	Simulation ($\bar{S}$)	Actual data ($\bar{A}$)
Order	5,466,933	5,432,526
Production	5,995,933	5,897,598

Fig. 6 demonstrates the production, order, and design capacity. Production is made based on demand (order) forecasting. In this research, we set expected order rate equal to 6% during the period of 1994–1997 and 1999–2008 (based on consideration that average order was ±6%) and −1% in 1998 based on management policy by considering the construction growth that had become negative at the time. Order reached 4.24 million tonnes in 1995, greater than the design capacity that was only around 4.1 million tonnes in 1994. It was therefore they need *Additional Capacity* to cover demand for the next future. Starting from 1995, firm expanded the design capacity to be 9.7 million tones by considering the market growth and the demand forecasting. Production was ±8.07 million tonnes in 2007 and reached 8.5 million tonnes in 2008. As, we can see from Fig. 6, starting from the year 2000, production was around 5% higher than order to provide inventory to cover cyclical and seasonal demand.

Fig. 7 represents production, shipment, and inventory during 1994–2008. Inventory will continue building up as long as production is greater than shipment. Fig. 8 shows the graph of inventory, stock, and export. During the period of 1998–1999, inventory reached around 1.66 million tonnes to 1.84 million tonnes due to the impact of the negative growth rates in construction, GDP, and investment. On average, inventory is only around 4.7% of production. A firm keeps 10% of accumulated inventory as stock, to meet the potential demand fluctuations. The rest of the 90% of inventory was exported to other countries.

4.2. Validation of simulation based model

Model validation constitutes a very important step in system dynamics methodology. To do this process, we need the historical data during the time horizon from 1994 to 2008. According to Barlas [2], a model will be valid if the error rate is smaller than 5% (see Eqs. (28)–(30)), where $\bar{S}$ represents the average of the simulation result, and $\bar{A}$ represents the average of the historical data.

In this research, we selected order and production variables to check the model validity based on consideration that order and production are significant for the base model and the availability of those data. From the base run results, we can obtain the average value of simulation for *Order* equal to 5,466,933 tonnes while the average value of simulation for *Production* equal to 5,995,933 tonnes. As we can see from Eqs. (28)–(30), in this validation process, we also need historical data of order and production. From the historical data of order and production, we obtained the average value of *Order* equal to 5,432,526 tonnes and the average value of *Production* equal to 5,897,598 tonnes as depicted in Table 3

$$\text{Error Rate} = \frac{|\bar{S} - \bar{A}|}{\bar{A}} \tag{28}$$

where

$$\bar{S} = \frac{1}{N}\sum_{i=1}^{N} S_i \tag{29}$$

$$\bar{A} = \frac{1}{N}\sum_{i=1}^{N} A_i \tag{30}$$

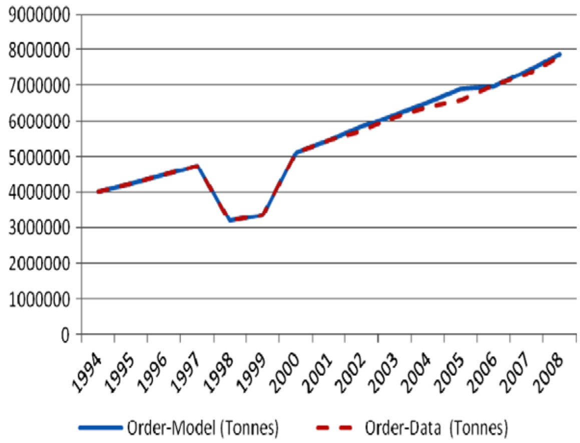

Fig. 9. Comparison between simulated order and historical data.

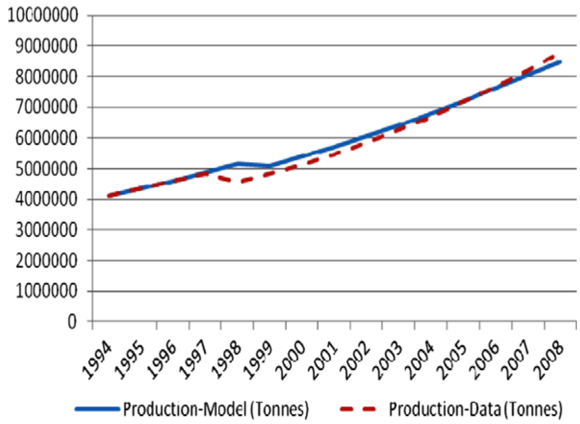

Fig. 10. Comparison between simulated production and historical data.

The error rates of *Order* and *Production* are given as follows:

$$\text{Error Rate of Order} = \frac{|5,466,933 - 5,432,526|}{5,432,526} = 0.006334$$

$$\text{Error Rate of Production} = \frac{|5,995,933 - 5,897,598|}{5,897,598} = 0.016674$$

Based on the above results, all the error rates are smaller than 5%, which means that our model is valid. The comparison between simulation results and historical data of *Order* and *Production* are given in Figs. 9 and 10, respectively.

5. Scenario development

In this section, we show how the system structure of a valid model can be changed by adding some feedback loops, adding new parameters, and changing the structure of the feedback loops (structure scenario), and how the parameter model can be changed to see the impact to other variables (parameter scenario). Scenario development is a prognosis method where the present data is used to develop various possible, often alternative future scenarios [20]. The scenario block diagram is given in Fig. 11.

5.1. Structure scenario

In this scenario, we modified the structure of order to forecast national demand, if demand is expected to grow with an average growth rate of around 7% based on the market analysis done by *Indonesia Economic Intelligence*. We developed two structure scenarios: the first one without capacity expansion and the second one with capacity expansion.

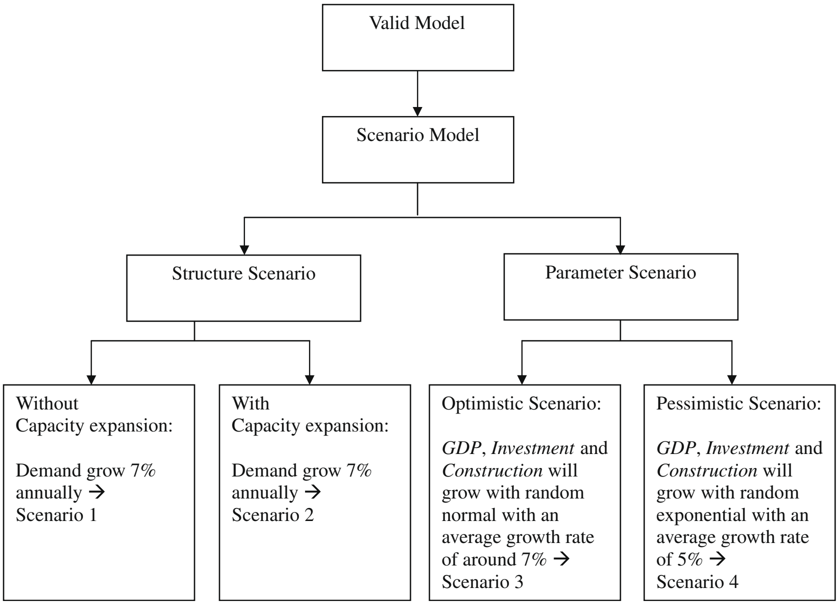

Fig. 11. Scenario block diagram.

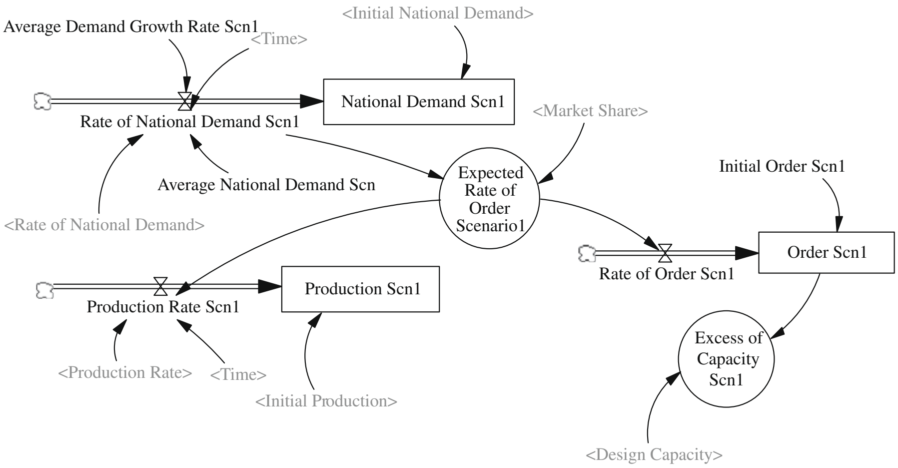

Fig. 12. Flow diagram of order if demand is expected to grow around 7% without capacity expansion.

5.1.1. Demand is expected to grow 7% annually, without capacity expansion

Fig. 12 shows the flow diagram of *Order* if demand is projected to grow around 7% annually, without capacity expansion. Based on this analysis, national consumption demand of cement would grow around 7% annually, in line with the economic growth [22]. Therefore, we set the *Average Demand Growth RateScn1* = 6 + RANDOM EXPONENTIAL() to obtain demand growth with exponential distribution of mean equal to 7% (see Eq. (31)). We utilized random exponential based on consideration that the probability of the growth of the demand declines as the size of the growth increases. *Expected Rate of Order Scenario*1 is restricted by the rate of national demand and the firm's market share (see Eqs. (32) and (33)). The amount of *Production* is determined based on the expected order (see Eq. (34)). *Excess of Capacity Scn1* depends on *Design Capacity* and *Order Scn1* (see Eqs. (35) and (36))

$$\text{Average Demand Growth Rate Scn1} = 6 + \text{RANDOM EXPONENTIAL()} \quad (31)$$

$$\text{Expected Rate of Order Scenario1} = \text{Market Share}^{*}\text{Rate of National Demand Scn1} \quad (32)$$

$$\text{Rate of National Demand Scn1} = \text{Average National Demand Scn}^{*}\text{Average Demand Growth Rate}/100, \quad \text{Rate of National Demand} \quad (33)$$

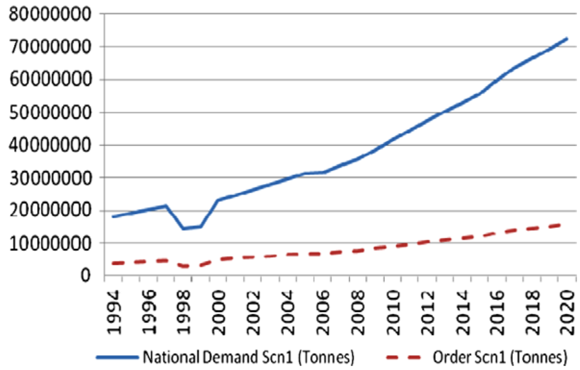

Fig. 13. National consumption demand and order scenario 1.

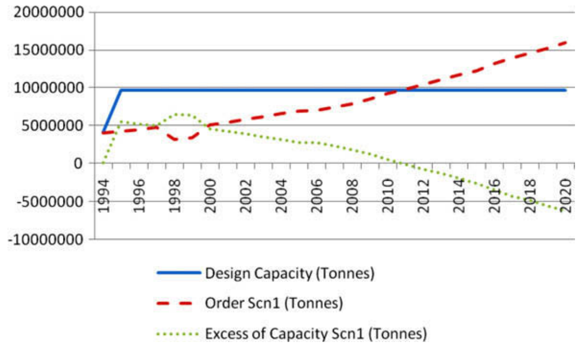

Fig. 14. Design capacity, order, and excess of capacity scenario 1.

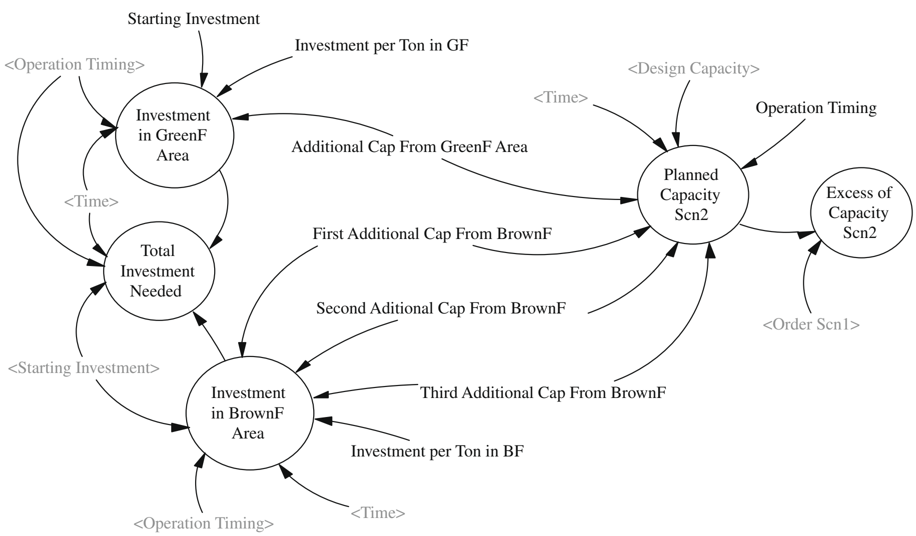

Fig. 15. Flow diagram of planned capacity expansion.

$$\text{Production Scn1}(t) = \text{Production Scn1}(t - dt) + (\text{Expected Rate of Order Scenario1})^* dt \quad (34)$$

$$\text{Excess of Capacity Scn1} = \text{Design Capacity} - \text{Order Scn1} \quad (35)$$

$$\text{Order Scn1}(t) = \text{Order Scn1}(t - dt) + (\text{Rate of Order Scn1})^* dt \quad (36)$$

Fig. 13 demonstrates the national consumption demand and order scenario 1. As we can see from Fig. 13, starting from 2011, national demand would be around 44.51 million tonnes and the firm's order would be around 9.8 million tonnes. Fig. 14

shows the *Design Capacity*, *Excess of Capacity Scn*1, and *Order Scn*1. As we can see from Fig. 14, there would be capacity shortage for around 92,975 tonnes starting from 2011 and would reach 6.24 million tonnes in 2020, which means that order would exceed the design capacity starting from 2011.

5.1.2. Demand is expected to grow 7% annually, with planned capacity expansion

This scenario is made to cover the future demand by considering planned capacity expansion. Fig. 15 represents the flow diagram of planned capacity expansion. The firm plans to start building two new plants with design capacity of 2.5 million tonnes each in 2008: one in the Greenfield area in Java and the other one in the Brownfield area in Sulawesi. These two new plants would be in operation by the year 2011. The design capacity in Greenfield area is 2.5 million tonnes and would be in operation with full capacity, that is, in 2011 there would be additional capacity of 2.5 million tonnes from the Greenfield area. For the Brownfield area, the design capacity is 2.5 million tonnes, which would be in operation gradually, with additional capacity of 1 million tonnes in 2011, 1.8 million tonnes in 2012 and 2.5 million tonnes in 2013.

By referring to the results of scenario 1, that capacity shortage would occur starting from 2011, we utilized *Order Scn1* as a feedback to scenario 2 to check the *Excess of Capacity Scn2* after the firm expands the design capacity (see Eqs. (37) and (38)). Investment per tonne in the Brownfield area is US$126 and in the Greenfield area US$142. Total investment needed during the building period will be equal to the summation of the investment in each area (see Eqs. (39)–(41))

$$\text{Excess of Capacity Scn2} = \text{Planned Capacity Scn2} - \text{Order Scn1} \tag{37}$$

$$\begin{aligned}
&\text{Planned Capacity Scn2} = \\
&\circ\ \text{IF THEN ELSE(Time} = \text{Operation Timing, Design Capacity} \\
&\quad + \text{Additional Cap From GreenF Area} + \text{First Additional Cap From BrownF}, \\
&\circ\ \text{IF THEN ELSE(Time} = \text{Operation Timing} + 1, \text{Design Capacity} \\
&\quad + \text{Additional Cap From GreenF Area} + \text{First Additional Cap From BrownF} + \text{Second Aditional Cap From BrownF}, \\
&\circ\ \text{IF THEN ELSE(Time} >= \text{Operation Timing} + 2, \text{Design Capacity} + \text{Additional Cap From GreenF Area} \\
&\quad + \text{Third Additional Cap From BrownF} + \text{Second Aditional Cap From BrownF} \\
&\quad + \text{First Additional Cap From BrownF, Design Capacity)))}
\end{aligned} \tag{38}$$

$$\begin{aligned}
\text{Investment in GreenF Area} = {} & \text{IF THEN ELSE(Time} >= \text{Starting Investment : AND : Time} < \\
& = \text{Operation Timing, Investment per Ton in GF}^{*}\text{Additional Cap From GreenF Area,0)}
\end{aligned} \tag{39}$$

$$\begin{aligned}
&\text{Investment in BrownF Area} = \\
&\circ\ \text{IF THEN ELSE(Time} >= \text{Starting Investment : AND : Time} \\
&\qquad <= \text{Operation Timing, Investment per Ton in BF}^{*}\text{First Additional Cap From BrownF}, \\
&\circ\ \text{IF THEN ELSE(Time} = \text{Operation Timing} + 1, \text{Investment per Ton in BF}* \\
&\quad \text{(First Additional Cap From BrownF} + \text{Second Aditional Cap From BrownF)}, \\
&\circ\ \text{IF THEN ELSE(Time} >= \text{Operation Timing} + 2, \text{Investment per Ton in BF}* \\
&\quad \text{(First Additional Cap From BrownF} + \text{Second Aditional Cap From BrownF} \\
&\quad + \text{Third Additional Cap From BrownF), 0)))}
\end{aligned} \tag{40}$$

$$\begin{aligned}
&\text{Total Investment Needed} = \\
&\circ\ \text{IF THEN ELSE(Time} >= \text{Starting Investment : AND : Time} \\
&\qquad <= \text{Operation Timing, Investment in BrownF Area} + \text{Investment in GreenF Area}, \\
&\circ\ \text{IF THEN ELSE(Time} = \text{Operation Timing} + 1, 3.55e + 008 + \text{Investment in BrownF Area}, \\
&\circ\ \text{IF THEN ELSE(Time} = \text{Operation Timing} + 2, 3.55e + 008 + 3.15e + 008, 0)))
\end{aligned} \tag{41}$$

Fig. 16 shows the graphs of *Order Scn*1, *Planned Capacity Scn*2, and *Excess of Capacity Scn*2. As we can see from Fig. 16, by expanding the design capacity, the firm will cover future demand until 2018, because by the year 2019, order is predicted to be around 15.25 million tonnes, while the design capacity only 14.7 million tonnes. Therefore, in 2019, again there would be capacity shortage for around 0.55 million tonnes as the effect of the demand growth.

Fig. 17 demonstrates the total investment needed during the building period. As we can see from Fig. 17, total investment needed to build the two new plants would be around US$670 million.

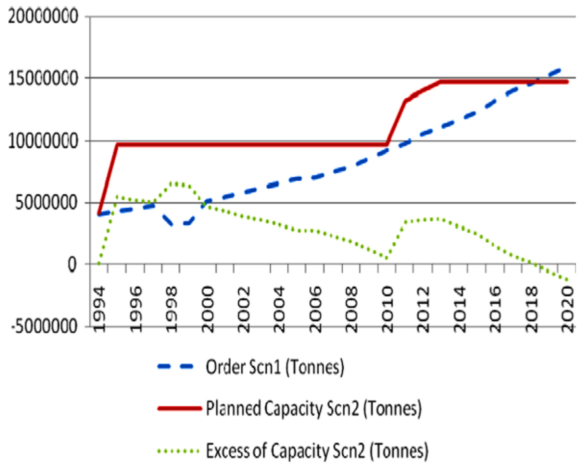

Fig. 16. Order scenario 1, planned capacity, and excess of capacity scenario 2.

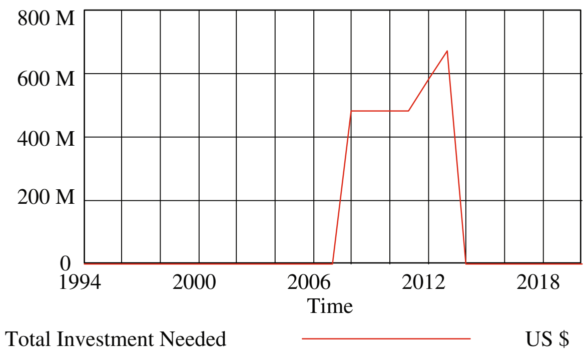

Fig. 17. Total investment needed for capacity expansion.

5.2. Parameter scenario

In this scenario, we developed optimistic and pessimistic scenarios to predict the future of demand. We modified the values of the GDP growth, investment growth, and construction growth by considering the optimistic and pessimistic conditions, to see the impact of the changes to the demand growth rate.

5.2.1. Optimistic scenario

This scenario is made to check whether the new design capacity (*Planned Capacity Scn2*) can meet the future demand, if GDP is predicted to grow around 7%, investment is projected to grow around 7% and construction is expected to grow around 7%. All these growth rates are set by considering Indonesia's promising economic outlook, that the prospect of some economic sectors may have better prospect than others. The most important number in the 2009 economic growth target is at 6.2% [4]. The flow diagram of order and excess of capacity optimistic scenario is given in Fig. 18. In this study, we utilized RANDOM NORMAL() functions to generate the fluctuations of GDP growth, investment growth, and construction growth based upon consideration that the variance of those growths is predicted to be around 1%. RANDOM NORMAL () provides a normal distribution of mean 0 and variance 1. To obtain a certain value of the mean we add a constant value to the function (see Eqs. (42)–(47))

$$\text{Average Investment Growth Optimistic Scn} = 7 \tag{42}$$

$$\text{Investment Growth Snc3} = \text{Average Investment Growth Optimistic Scn} + \text{RANDOM NORMAL}() \tag{43}$$

$$\text{Average GDP Growth Optimistic Scn} = 7 \tag{44}$$

$$\text{GDP Growth Scn3} = \text{Average GDP Growth Optimistic Scn} + \text{RANDOM NORMAL}() \tag{45}$$

$$\text{Average Construction Growth Optimistic Scn} = 7 \tag{46}$$

$$\text{Construction Growth Scn3} = \text{Average Construction Growth Optimistic Scn} + \text{RANDOM NORMAL}() \tag{47}$$

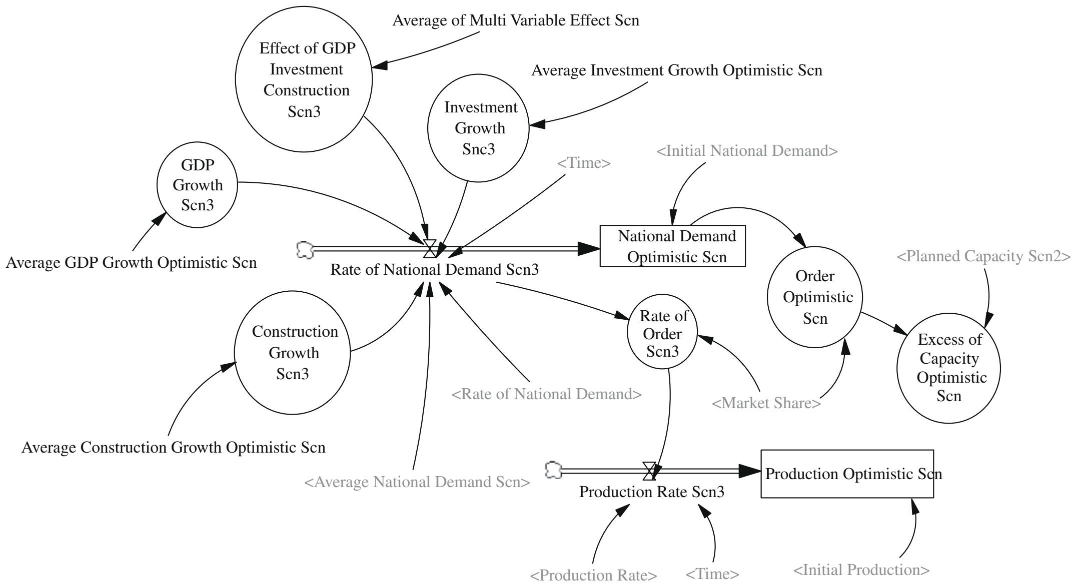

Fig. 18. Flow diagram of order and excess of capacity optimistic scenario.

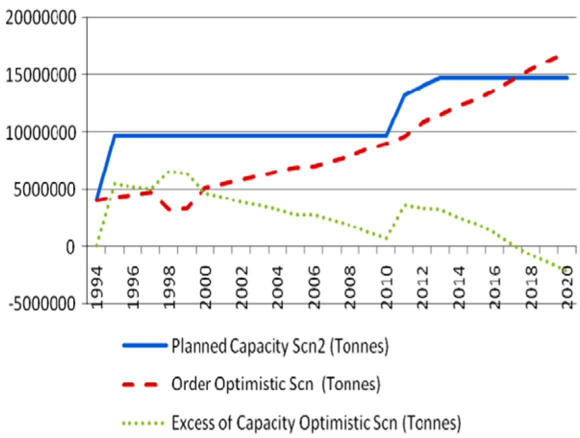

Fig. 19. Planned capacity, order and excess of capacity optimistic scenario.

National demand Optimistic Scn is restricted by the *Rate of National National Demand Scn3*. *Rate of National National Demand Scn3* would increase, in line with the growth of the optimistic projections of GDP, investment, and construction. *Effect of GDP Investment Construction Scn3* represents the effect of the growth of GDP, investment, and construction to the *Rate of National National Demand Scn3* (see Eqs. (48)–(50)). *Order Optimistic Scn* depends on *Market Share* and *National Demand Optimistic Scn*. Excess capacity would happen as long as the *Planned Capacity Scn2* is greater than *Order Optimistic Scn* (see Eqs. (51)–(53))

$$\text{Rate of National Demand Scn3} = \text{Construction Growth Scn3}/100^{*}\text{GDP Growth Scn3}/100^{*}\ \text{Average National Demand Scn}^{*}\text{Investment Growth Snc3}/100^{*}\text{Effect of GDP Investment Construction Scn3} \tag{48}$$

$$\text{Effect of GDP Investment Construction Scn3} = \text{Average of Multi Variable Effect Scn} + (10^{*}\text{RANDOM NORMAL}()) \tag{49}$$

$$\text{Average of Multi Variable Effect Scn} = 250 \tag{50}$$

$$\text{National Demand Optimistic Scn}(t) = \text{National Demand Optimistic Scn}(t - \mathrm{d}t) + (\text{Rate of National Demand Scn3})^{*}\mathrm{d}t \tag{51}$$

$$\text{Order Optimistic Scn} = \text{Market Share}^{*}\text{National Demand Optimistic Scn} \tag{52}$$

$$\text{Excess of Capacity Optimistic Scn} = \text{Planned Capacity Scn2} - \text{Order Optimistic Scn} \tag{53}$$

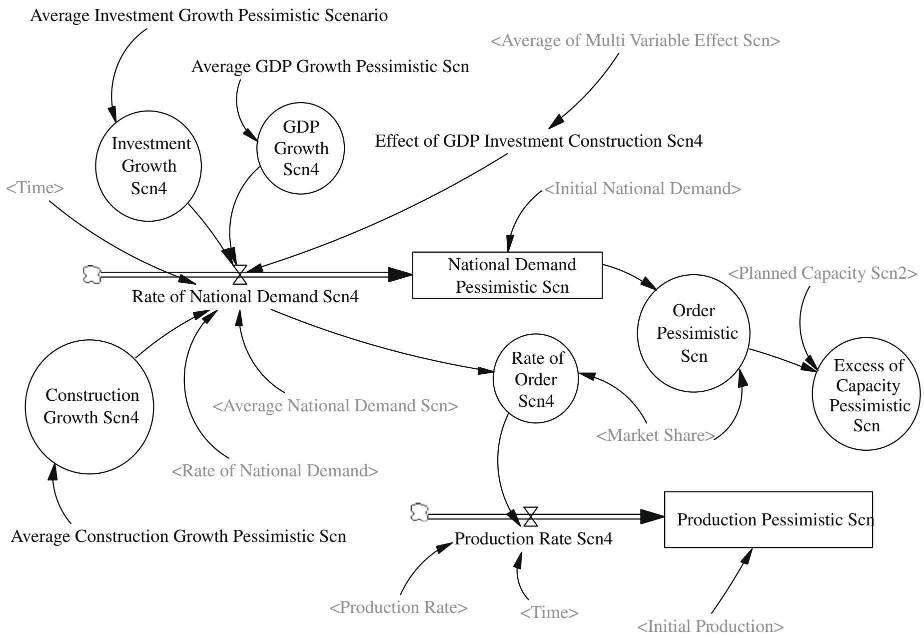

Fig. 20. Flow diagram of order and excess of capacity pessimistic scenario.

Fig. 19 represents the planned capacity expansion, excess of capacity optimistic scenario, and order optimistic scenario. As we can see from Fig. 19, with planned capacity expansion, there would be additional capacity of around 3.5 million tonnes in 2011, 4.3 million tonnes in 2012, and 5 million tonnes in 2013. Therefore, by the year 2013, the total design capacity would be around 14.7 million tonnes. With this planned capacity expansion and favorable economic condition, the firm can fulfill the market demand until 2017. Order is predicted to be around 14.54 million tonnes in 2017 and would reach around 15.47 million tonnes in 2018. Based on this projection, starting from 2018, there would be capacity shortage for around 770,000 tonnes. Again, the firm should expand the capacity to meet the demand for the future.

5.2.2. Pessimistic scenario

This scenario is generated to check whether the new design capacity (*Planned Capacity Scn2*) can meet the future demand, if national economic growth slows down to around 4%. GDP, investment and construction are projected to grow at around 4.4%, 4.5% and 4%, respectively. All these growth rates are set based on the World Bank forecast in which Indonesia's economic growth may slow down to 4.4% in 2009 [27]. The flow diagram of *Order* and *Excess of Capacity Pessimistic Scn* is given in Fig. 20.

We modified the fluctuations of GDP growth, investment growth, and construction growth to be around 4%. We then set the fluctuations of these three variables by utilizing RANDOM EXPONENTIAL() to provide exponential distribution with a mean of 1 (see Eqs. (54)–(59)). We utilized random exponential based on consideration that the probability of the growth of the demand declines as the size of the growth increases

$$\text{Average GDP Growth Pessimistic Scn} = 4.4 \tag{54}$$

$$\text{GDP Growth Scn4} = \text{Average GDP Growth Pessimistic Scn} + \text{RANDOM EXPONENTIAL()} \tag{55}$$

$$\text{Average Investment Growth Pessimistic Scenario} = 4.5 \tag{56}$$

$$\text{Investment Growth Scn4} = \text{Average Investment Growth Pessimistic Scenario} + \text{RANDOM EXPONENTIAL()} \tag{57}$$

$$\text{Average Construction Growth Pessimistic Scn} = 4 \tag{58}$$

$$\text{Construction Growth Scn4} = \text{Average Construction Growth Pessimistic Scn} + \text{RANDOM EXPONENTIAL()} \tag{59}$$

National Demand Pessimistic Scn is restricted by the Rate of National National Demand Scn4. Rate of National National Demand Scn4 will decline, in line with the slow growth rates of GDP, investment, and construction. Effect of GDP Investment Construction Scn4 represents the effect of the growth of GDP, investment, and construction to the Rate of National Demand Scn4 (see Eqs. (60) and (61)). Order Pessimistic Scn depends on Market Share and National Demand Pessimistic Scn. Excess capacity would happen as long as the Planned Capacity Scn2 is greater than Order Pessimistic Scn (see Eqs. (62) and (63)).

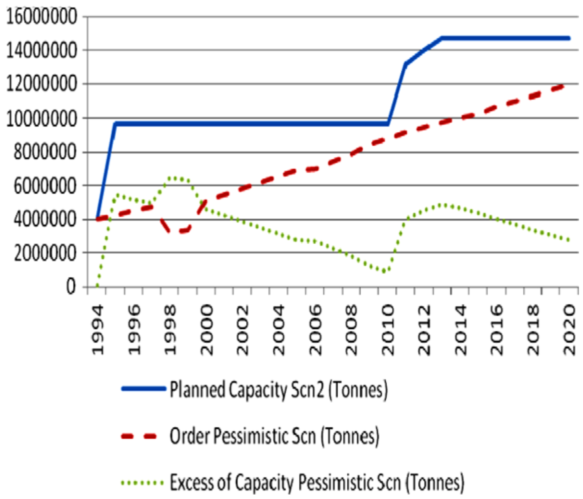

Fig. 21. Planned capacity, order and excess of capacity pessimistic scenario.

Table 4
Summary table of scenarios run results.

Scenario type	Year	Firm order (Tonnes)	Additional capacity expansion (Tonnes)	Current capacity (Tonnes)	Excess of capacity (Tonnes)
Structure scenario					
Without capacity expansion (demand is expected to grow 7% annually)	2011	9,792,000	–	9,700,000	−92,000
	2012	10,440,000	–	9,700,000	−740,000
	2013	11,010,000	–	9,700,000	−1,310,000
	2019	15,250,000	–	9,700,000	−5,550,000
	2020	15,940,000	–	9,700,000	−6,240,000
With capacity expansion (demand is expected to grow 7% annually)	2011	9,792,000	3,500,000	13,200,000	3,408,000
	2012	10,440,000	800,000	14,000,000	3,560,000
	2013	11,010,000	700,000	14,700,000	3,690,000
	2019	15,250,000	–	14,700,000	−550,000
	2020	15,940,000	–	14,700,000	−1,240,000
Parameter scenario					
Optimistic scenario *GDP*, *investment* and *construction* will grow with random normal with an average growth rate at 7%	2011	9,625,000	3,500,000	13,200,000	3,575,000
	2012	10,730,000	800,000	14,000,000	3,270,000
	2013	11,490,000	700,000	14,700,000	3,210,000
	2018	15,470,000	–	14,700,000	−770,000
	2020	16,920,000	–	14,700,000	−2,220,000
Pessimistic scenario *GDP*, *investment* and *construction* will grow with random exponential with an average growth rate at 5%	2011	9,198,000	3,500,000	13,200,000	4,002,000
	2012	9,475,000	800,000	14,000,000	4,525,000
	2013	9,787,000	700,000	14,700,000	4,913,000
	2018	11,310,000	–	14,700,000	3,390,000
	2020	11,920,000	–	14,700,000	2,780,000

$$\text{Rate of National Demand Scn4} = \text{Construction Growth Scn4}/100 * \text{GDP Growth Scn4}/100^{*} \quad \text{Average National Demand Scn} * \text{Investment Growth Scn4}/100 * \text{Effect of GDP Investment Construction Scn3} \tag{60}$$

$$\text{National Demand Pessimistic Scn}(t) = \text{National Demand Pessimistic Scn}(t - dt) + (\text{Rate of National Demand Scn4}) * dt \tag{61}$$

$$\text{Order Pessimistic Scn} = \text{Market Share} * \text{National Demand Pessimistic Scn} \tag{62}$$

$$\text{Excess of Capacity Pessimistic Scn} = \text{Planned Capacity Scn2} - \text{Order Pessimistic Scn} \tag{63}$$

Fig. 21 represents the *Planned Capacity Scn2*, *Excess of Capacity Pessimistic Scn*, and *Order Pessimistic Scn*. As we can see from Fig. 21, with planned capacity expansion and slow growth in economic condition, the firm's production might always satisfy the market demand at least until 2020. Excess capacity in 2020 would be around 2.78 million tonnes, order would be only around 11.92 million tonnes, indicating that the demand would still be under the planned capacity. We summarized all the scenario results in Table 4.

These scenarios have been developed by modifying the structures and the parameters of the valid model to provide some possibilities that might happen in the future and to guide the firm's management in developing capacity planning. By forecasting the demand (order), the real risks (e.g., excess capacity, capacity shortages) can be avoided. Capacity expansion is required since excess of capacity becomes negative. The most artistic phase of the system dynamics modifies the feedback loop structure to suppress the undesirable behavior modes and to generate the desirable ones. Based on this concept, we developed structure scenarios by utilizing *Order Scn1* as a feedback to scenario 2 (demand is expected to grow 7% annually, with capacity expansion) to check the planned capacity coverage for the future demand (order). According to these results, we know that if the demand grows 7% annually with planned capacity expansion, the firm can cover the demand until 2018. However the firm has to make another design capacity expansion in 2019 to meet future demand.

In this research, we also developed parameter scenarios to provide a more reliable forecast to cover all the uncertain conditions in the future. We forecast the demand (order) based on optimistic and pessimistic projections (that might happen related to *GDP, Investment* and *Construction Growths*) to provide warning, risks or alternative scenarios. From the summary table in Table 4, we can obtain that if *GDP*, *Investment*, and *Construction Growths* grow with average growth rate at 7% (optimistic projection) and with planned capacity expansion, the firm can cover the demand until 2017. Starting from 2018, however, the firm should expand the design capacity again to meet future demand. Meanwhile, if *GDP*, *Investment*, and *Construction Growths* grow with average growth rate at 5% (pessimistic projection) and with planned capacity expansion, the firm can cover the demand, at least, until the year 2020.

6. Conclusion

This paper provided a method for developing models to forecast cement demand and scenarios of planned capacity expansion to meet the future demand based on optimistic and pessimistic economic projections. These models can provide important inputs such as construction growth, GDP growth, investment growth, and effect of multi variables (GDP, investment, and construction growths) to specific business decisions such as planned capacity expansion policies that will improve the system performance. Every decision or policy is based on some assumptions, or forecast, about the future. In this research we assumed that demand for cement will grow as general economic trends were positive for the cement industry. Assumptions about future demand are essential for planned capacity expansion decision, for example: how much capacity is required, when to expand the capacity and how much investment is needed. With the detailed and calibrated model, the peak and subsequent downturn of demand can be accurately predicted. As a result, unnecessary capacity expansion can be avoided because the future demand can be accurately predicted.

The important aspect of the system dynamics framework is that it focuses on information feedback control to organize the available information into computer simulation models. By using a feedback structure, the existing conditions of the system can lead to decisions that will change the surrounding conditions and will influence the next decisions. In creating system dynamics models, information is used as the basic building blocks for the models (see Section 3). The successfulness of a model depends on a clear identification of the important purposes of the model. The model should help us to organize information in a more understandable way, and link the past condition into the present one (see Section 4.1) and extend the present into future alternatives through scenarios development (see Section 5). Understanding of the dynamics behavior and full sensitivity tests by developing some scenarios will allow us to determine those uncertainties to which the forecast is most sensitive and what might cause demand to change in such a way to provide more reliable, or better forecast and scenarios under condition of uncertainties to make a better decision.

This study could be considered as a pilot study to decide when the manufacturing decision maker should expand the design capacity to meet future demand. There are several areas where further research is still required. One is revenue and performance management where firms need to expand the design capacity to meet the growing demand. Another area is in the manufacturing strategy that will relate Sales and Operations Planning (S&OP) to the longest-term planning level in a Manufacturing Planning and Control (MPC) system. Also in manufacturing planning, it is essential to link functions such as business planning, sales, and operations planning with structural and infrastructural decisions categorized by the manufacturing strategy framework.

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