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Dynamic analysis of resiliency and sustainable production system

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A look at the world production and consumption indicates that production systems resiliency and sustainability is highly regarded by businessmen and the general users for long surviving of human being race and ecological endurance. By conducting theoretical studies and reviewing the literature, and searching previous studies to identify the resilience factors important to manufacturing industries, a list of effective strategies was determined. The most important strategies of resilience considered in this study are: capacity management, multi sourcing, demand management, information sharing, additional inventory holding, contracting with backups, risk management and disaster recovery, dropping market feeding strategy, enlightenment of business flow complexity, and suppliers/facilities reinforcement. In this article, DEMATEL approach is used to demonstrate how production resilience factors can impacts on each other and what the interrelationships among these factors are. After that, a questionnaire was designed for pairwise comparisons of resilience strategies of capacity scaling, multi sourcing, contracts, inventory management, risk management, and production level. Then, a system dynamics approach is used to model the interrelations among the resilience factors by taking feedback loops into consideration managing to trace their impacts on production and inventory levels. A production system with its main processes of: production order rate, planned work, work in process (WIP), production rate, inventory level, desired shipment rate, backlogs, rejected rate, rework rate, required capacity, and capacity scaling are designed for this study. This model presents a production system with circular resilience's strategies impacts on production scaling and hence their impacts on sustainability indicators of job creation, and salary (social pillar), profit and investment (economic pillar), and ecosystem destruction (environment pillar). System dynamics approach helped us in presenting the long trends of sustainability indicators as shown by a number of figures in the body of this article. Five scenarios are developed and the results were presented to the team of our experts presenting them by wi=0, wp=0 (case 1), wi=0, wp=0.5 (case 2), wi=1, wp=0 (case 3), wi=0, wp=1 (case 4), and wi=0.36, wp=0.47 (case 5). Experts' opinions were gathered and then use TOPSIS approach for determining the best case the among cases discussed above. The results indicates that the data generated by Vensim computer software for five cases, case 5 with wi=0.36 and wp=0.47 is the best case among all cases.

***Keywords**: Causality analysis, resilience factors, production system, dynamic approach*

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1. Introduction

Systems are always vulnerable to various types of disruptions raging from natural disasters, human errors, human misguiding, unpredicted accidents, terrorism based and economic related. In all these cases, system is damaging and the investment and people working in that as well. Systems as such as supply chain, production, distribution canals, and transshipment systems are as such with high vulnerability. Pettit, Fiksel et al. [22] reported in their research that resilience capability facilitates a supply chain returning to its original state following disruptions. On the other hand, Christopher & Peck [10] and Ponomarov & Holcomb [53] argue that one way to prepare for unexpected events and responding to disruptions is through systems' resilience capability. No single capability of a system can be sufficient enough to mitigate all disruption and possible vulnerabilities. This means that it is not an easy task to determine which capability of the system should be focused on to give it higher priority for management team to having eye on and

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keep watching it performance. As Fiksel [21] stated, resiliency refers to a firm's capacity to survive, adapt and grow in the face of change and uncertainty. Methodologies for determining the impacts of unpredicted events in a system are the use of optimization techniques, simulation, and optimization-simulation approaches.

For the first time the term of resilience in supply chain was suggested by Sheffi [67] which is the capability of a system for returning to its original state when it is disrupted under some circumstances. Many definitions have been presented for resilience by various researchers. Most studies have defined resilience as the "degree of sustainability of system". This concept has been applied in several disciplines including economics, politics, engineering, and planning. A definition given for resiliency is: "Resilience can be understood as the ability of the system to reduce the chances of a shock, to absorb a shock if it occurs (abrupt reduction of performance) and to recover quickly after a shock (re-establish normal performance)".

A profitable production system which is at the edge of competitive advantage with skilled management team can survive for a long time to come. Usually, such systems are ready to deal with external risks and disruptions. In this article, authors use the interrelationships among the system resilience factors to study their impacts on the sustainability indicators. We would like to show that a force implied by the dynamics of these factors have the highest impacts on the sustainability indicators both positively and negatively. We always can study the impacts of one or more than one resiliency factors on the systems' performance through sustainability indicators. For this purpose, we can evaluate a domain from a business perspective such as profitability or a socio-ecological perspective taking sustainability indicators into consideration. As authors argue 'transitions between desirable and undesirable domains have been analyzed for more than thirty years as part of the development of resilience theory (Gunderso [24]; Van de Brugge [76].' More on this can be seen in the work of Rydzak and Chlebus [59]. Stolz [69] argues that 'resilience is the only sustainable and portable strategic plan. Resilient individuals, teams, and organizations consistently outlast, outmaneuver and outperform their less resilient competitors'.

Salehi et al. [63] designed a resilient and sustainable biomass supply chain network using an optimization type model based upon the uncertainty in bio-energy demand and the disruption in the bio-refinery. Authors employed fuzzy TOPSIS approach to related resilience factors into sustainability indicators to determine the most influential resilience factor for consideration in the mathematical modeling of the problem. The objective function of problem is of maximization type. Zare Mehrjerdi and Lotfi [80] studied a resilient and sustainable closed loop supply chain taking value at risk and robust optimization approach for problem solving. Shafiei, et al. [66] conducted research on lean, sustainability and resiliency in supply chain using stochastic programming for back up supplier selection. The proposed model is solved by e-constrained method. Zare Mehrjerdi and Shafiee [75] conducted research on sustainable closed-loop supply chain network design in Tire industry. A key resilient strategy known as multi-sourcing was considered in the mathematical modeling of the problem using a multi criterion decision making approach. The resulting mathematical model of the problem was solved by e-constrained approach.

Many researchers have employed resilience factors in supply chain and manufacturing modeling. But what is lacking in all these researches are listed below:

1. What are key resilient factors important to production system?
2. Considering key resilience factors in one integrated modeling to observing how such factors impacts on each other using DEMATEL approach.
3. Drawing a causal diagram showing how factors impacting and receiving impacts from other factors.
4. Developing a system dynamic model using Stock and Flow diagram to simulate the model resulting from step 3.
5. Utilizing fuzzy sets to deal with the ambiguity of experts' opinions.
6. Integration of resiliency factors and sustainability indicators for determining a new structure as a dynamic hypothesis of problem using fuzzy DEMATEL approach.
7. Consideration of capacity scalability within the framework of system sustainability and resiliency

The remaining of this article is organized as below. Section 2 is devoted to the research background which discusses system dynamics, capacity scalability, criteria dependency, production system, resiliency, fuzzy DEMATEL, and sustainability. Section three discusses resilience strategies or factors. The fuzzy DEMATEL results of ample case are presented in section 4. System dynamics model of the problem is discussed in section 5 while production control under dynamics of resilience factors is discussed in section 6. Simulation results presentation and discussion are discussed in section 7. Production sustainability indicators are presented in section 8. Capacity scaling results are shown in section 9 while implications are discussed in section 10. Author's conclusion is given in section 11.

2. Research Background

2.1 System dynamics

Systems thinking (ST) and system dynamic (SD) are two branches of science that are closely related to one other. ST helps in developing interrelationships among main factors and generating reinforcing and balancing loops to elaborate system's performance and variables' behavior along times, using well defined structured relating to patterns presented in the literature. SD as an extension of ST can be used for generating goal variables' behaviors and analyzing them. This technique can help us to deeply understanding the interactions exist among physical processes, the flow of information and the policies that management may want to get hands on them. The outputs of this type of modeling are optimal policies or strategies. Systems' structure can be built using main variables of systems along with the relationships exit among the variables. When such structure simulates over time the dynamic behaviors of goal variables can be demonstrated.

Vlachos et al., [73] claim that 'SD model provides a valid description of the real world processes and search for best ways to improve the system performance.' As Chaerul and his co-researchers [9] mentioned 'this method is particularly suited in complex systems, because it is capable of dealing with different assumptions about system structure.' SD has been employed for a wide assortment of problems, from teaching concepts to students in engineering, health, environment, agricultural, land management, and psychological schools. Hjortha & Bagheri [28] showed that system dynamics approach and its causal loop diagrams can be used to identify different dynamic structures in the real world.

The structure of SD is usually shown by CLD which is known as causal loop diagram. The CLD looping structure development is usually troublesome for the beginners. However, researchers once get hands on that, they will see that it is relatively simple for solving small to very large, complex, and sophisticated problems. To start modeling a problem proposing a dynamic hypothesis (DH), either graphically or verbally, is a must. Most often, DH is sketched by a diagram having two or three loops using main factors/ variables of the system to be studied. The primary assumption of system dynamics is that the structure of the system leads to its behavior. The better the structure of the system build the better the behavior can expect of the system. Better behavior means a behavior that is tremendously close to the systems' real behavior. Since system's behavior relates to the performance of its "Level Variables", SD can present one or more behaviors of the system.

System dynamics is used in joint with other approaches of decision making. Yiyun Liu et al. [77] have conducted research on hybridizing multi-objective optimization and system dynamics simulation for straw-to-electricity supply chain management under the belt and road initiatives. Orji and Liu [47] have proposed an approach for integrating MADM and system dynamics approaches. This approach are employed in the works of Amiri el al. [4], Salehi [63] to mention a few. Shahabadi and Zare Mehrjerdi [91] designed a system dynamics model to evaluate rice production system considering resilience and sustainability indicators. Abazari and Zare Mehrjerdi [92] conducted a study on the topic of sustainability indicators in mineral industries by hybridizing lean approach based upon the innovation, and system dynamics approach.

2.2 Production system

Over the years, industrial systems have tried to compete on many instances of cost cutting, efficiency increment, process change and improvement, employees training and development, and productivity enhancement. All these had helped production management in increasing profit and decreasing costs. Now in current industrial age, most systems that are working in the distributed collaborative workspace have very efficient structures. In this regard, Some authors argue that '*efficient'* systems happened to be '*fragile'* because of not being *resilient* to the disruptions of their normal operations.

In a daily work, production system deals with many activities including production planning, machin scheduling, on time producing, employees training, managerial supports, raw material quality check, supplier's on time delivery, demand pattern, late employees, and returning broken machines into production lines. Hence, we can say that production resiliency depends upon the resiliency of one or all of these functions as various kinds of disturbances may affect them. Although, many researchers as such as Horne [30], Hamel and Välikangas [26], Rice and Caniato [57], Stoltz [69], Christopher and Peck [10], and Sheffi [67] concentrated on the concepts of production resiliency but a clear picture of how to assess the resiliency is often not discussed deeply. There are some system characteristics that help us in assessing the level of resiliency of system, in general. They are:

1. How much changes can be made into the system where system still keeps its original configuration?
2. How much system can self-organize itself?
3. To what degree, system can build its capacity to learn and adapt?

2.3 Capacity Scalability

To gain understanding of scalability, we refer to the definitions given by authors in literature. Spicer and his co-workers [68] defined scalability "as ability to adjust the production capacity of a system using system reconfiguration having minimum cost and minimum time over a large capacity at given capacity increment “.

Koren [37] discusses System scalability as “the design of a manufacturing system and its machines with adjustable structure that enable system adjustment in response to market demand changes. Structure may be adjusted at the system level (e.g., adding machines) and at the machine level (changing machine hardware and control hardware)”.

Ghosh [23] stated that “Scalability implies that where the problem size increases, the algorithm continues to apply and by increasing the number of computational engines proportionately, the performance of the algorithm will continue to increase”.

Rys [61] defined that “computational scalability refers to operations on the data that should be able to scale for both an increasing number of users and increasing data sizes”.

As described in the literature by Deif and ElMaraghy [14-15] capacity scalability is simply the

1. Ability to adapt to changing demand
2. When, where, and by how much should the capacity of the manufacturing system be scaled
3. How much reduction of capacity is necessary?
4. How much capacity expansion is necessary?

To address capacity scalability planning for production system, we must provide response to the question 2 stated above. There are two ways to reach capacity scalability as discussed below:

(1) by scaling the capacity of individual manufacturing resources (ElMaraghy & Wiendahl [19]; Tolio et al.[71]
(2) by adding or removing manufacturing resources to or from existing in-house systems (Dazhong Wu, David W. Rosen. [12].

Perhaps the best way is subcontracting or out-sourcing part of the manufacturing tasks that are beyond the existing in-house capacity to third party (Dazhong Wu, David W. Rosen. [12].

2.4 Dependency treatment

Criteria dependency can be categorized into structural dependency and causal dependency.

2.4.1 Structural dependency: Structural dependency includes approaches as well as: (1) Analytical hierarch process (AHP), (2) Analytical network process (ANP) and (3) Hierarchical TOPSIS.

2.4.2 Causal dependency: Causal dependency approaches includes: (1) causal Maps, (2) DEMATEL, (3) Fuzzy cognitive Maps, (4) Bayesian Networks, (5) System dynamics, (6) Interpretive structural Modeling, (7) Structural Equation Modeling.

In this study, DEMATEL approach is employed to determine the causal relationships between factors of the production problem planning within the system resiliency and sustainability.

2.5 Sustainability

As far as sustainability of systems is concerned, there are two considerations here. The first is with regard to the raw materials to keep the system working on and the second is about the overall system sustainability. There are some studies available on the first and second matters as Table 1 shows. Salehi et al. [63] have

worked on the first situation while Amiri et al. [3, 4] have studied the second situation. Dehghani and Mansour [13] designed a sustainable recovery network of end-of-life products. Alirezaei et al. [2] have designed a resilient and sustainable supplier selection model. Devika and Nourbakhsh [17] conducted research on the sustainable closed loop supply chain based upon the triple bottom line approach. Assessing sustainability performance of large supply chain using system dynamics approach is studied by Izadyar et al. [35]. An efficient and sustainable closed loop supply chain is studied by Moheb-Alizade et al. [44]. Yunguang et al. [78] proposed an approach for assessing sustainability of Chinese iron and steel firms. On circular economy and resilience, Steve Kennedy [64] have proposed a research agenda on the topic of sustainability.
The three pillars of sustainability as discussed in the literature are discussed briefly below:

2.5.1 Economical This relates to the financial-economic feasibility and practicality. It does concerns with all aspects of growths, competition, market expansion, job creation, investments, productivity, and profitability. In organizational language, it relates to the capacity, capability, and expertise of human capital and the product it produces and the cash in-flows-cash out-flows that generates and the chances of survival of that financial system.

2.5.2 Environmental

This relates to the concept of environment and its direct impact on the system and vice versa. Due to the fact that usually organizations have negative impacts on the environment, policies to be implemented to make certain that the environmental concerns and the expenses that it would have for the society are fully covered. The organizational approach and its impacts on the neighboring systems and environment are of main concerns here.

2.5.3 Social

This pillar of sustainability plays a big role in presenting an organization to the society and how it can impact on the well-being of the society. It concerned with the type of products it makes, the type of jobs it generates, and the employees' level of pay and benefits. Also, issues such as human development, equity and ethics are of main concerns.

2.6 Resiliency

For the first time, the term of resilience in supply chain was suggested by Sheffi [67] which is the capability of a system for returning to its original state when it is disrupted under some circumstances. This means that when one or more internal or external factors cause changes in the state of the system, how much our system is capable of returning to its original state just before disturbance hit. Some authors have defined resiliency as the "degree of sustainability of system". This indicates that resiliency should be measured against the sustainability indicators. This way of thinking utilized in economics, politics, engineering, and planning disciplines. A definition in this regard is*: "r*esilience is the ability of groups or communities to cope with the external stresses and disturbances as a result of social, political, and environmental change". There are other ways to look at this phenomenon as this author thinks. How resiliency factors interrelationships (i.e., their causal impacts on each other) can produce a situational dynamic to impact systems' sustainability indicators. This idea guides us to dynamically study causal impacts of resilience factors and then applying its resulting force on sustainability indicators. Carvalho et al. (2012) [8] have conducted research for designing supply chain using simulation approach. Jabbarzadeh et al. [34] studied resilient and sustainable supply chain under disruption risk. Resilience supplier selection and optimal order allocation under disruption risk is the topic of research that Hosseini et al. [33] have worked on. Mousavi et al. [46] designed a robust supply chain for bioethanol considering system sustainability and resiliency under operational disruption risks. Pettit et al. [52] proposed a framework ensuring supply chain resiliency. Wang et al. [86] studied the performance of resilient supply chain sustainability in Covid-19 by sourcing technological integration.

2.7 Fuzzy set

Fuzzy set theory translates linguistic terms such as good, very good, poor, and very poor into fuzzy numbers (Rahayua & Wulandarib, 2022) [55]. A fuzzy number $\tilde{t} \in [0,1]$ is a triangular fuzzy number (TFN) if its membership function is:

$$\mu_{\tilde{t}} = \begin{cases} 0, x \leq a \\ \frac{x-a}{m-a}, a < x < b \\ \frac{c-x}{c-b}, b < x < c \\ 0, x > c \end{cases} \quad (1)$$

where a, b and c are called the lower bound, the mode and the upper bound of the triangular fuzzy (Iç & Yurdakul [32]. Using this representation, we can do arithmetic operations on fuzzy numbers very simple and quick. With the notations given above the arithmetic operations of (+), (-), (x), and (÷) on fuzzy numbers are defined as follows:

$$(a_1, b_1, c_1)(+)(a_2, b_2, c_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2)$$

$$(a_1, b_1, c_1)(-)(a_2, b_2, c_2) = (a_1 - c_2, b_1 - b_2, c_1 + a_2)$$

$$(a_1, b_1, c_1)(x)(a_2, b_2, c_2) = (a_1 x a_2, b_1 x b_2, c_1 x c_2)$$

$$(a_1, b_1, c_1)(\div)(a_2, b_2, c_2) = (a_1 \div c_2, b_1 \div b_2, c_1 \div a_2)$$

2.8 Fuzzy DEMATEL

Researchers have applied various multi attributed decision making (MADM) tools to make decisions on timely manner in both good and service industries. Approaches as such as Fuzzy TOPSIS [3, 47, 63, 83], VIKOR [83], DEMATEL [20, 63] are employed many times by researchers as well this author. DEMATEL as a tool for decision making was introduced into the literature by Battelle Memorial Institute of Geneva in 1976 and extended into fuzzy DEMATEL by authors Lin and Wu [39] for determining the cause and effects relationships among variables. The seven steps of this technique are discussed in the section that follows. Faregh et al. [20] employed fuzzy DEMATEL approach for assessing hotel's satisfaction trends using system dynamics approach.

Step 1: Relation matrix generation

To deal with the ambiguity and uncertainties linguistic variable are used on scales given in Table 1. A decision matrix of n x n using k experts' opinion by gathering data through a questionnaire is generated. The responses of these k experts help us to develop k tables with fuzzy elements. After converting each fuzzy decision table then k tables are added up and the average value for each cell is calculated.

Table 1: linguistic terms, signs and values

Linguistic description	Sign	Value
Very low	VL	(0, 0, 0.1)

Low	L	(0.1, 0.2, 0.2)
Medium Low	ML	(0.2, 0.3, 0.4)
Medium	M	(0.4, 0.5, 0.5)
Medium High	MH	(0.5, 0.6, 0.7)
High	H	(0.7, 0.8, 0.8)
Very High	VH	(0.8, 0.9, 1)

Hence, we use the arithmetic mean of all experts' opinions to generate the direct relation matrix Y as shown below.

$$Y = \begin{bmatrix} 0 & \cdots & \tilde{Y}_{n1} \\ \vdots & \ddots & \vdots \\ \tilde{Y}_{1n} & \cdots & 0 \end{bmatrix} \quad (2)$$

Step 2: Matrix normalization

The normalized fuzzy direct-relation matrix can be obtained using the following formula:

$$\tilde{x}_{ij} = \frac{\tilde{Y}_{ij}}{s} = \left(\frac{a_{ij}}{s}, \frac{b_{ij}}{s}, \frac{c_{ij}}{s}\right)$$

where

$$s = \max_{i,j}\left\{\max_i \sum_{j=1}^{n} c_{ij}, \max_j \sum_{i=1}^{n} c_{ij}\right\} \qquad i,j \in \{1,2,3,\dots,n\} \quad (3)$$

Step 3: Total relation matrix calculation

In step 3, a matrix called total relation matrix in fuzzy environment is calculated using following formula:

$$\tilde{T} = \lim_{k\to+\infty}(\tilde{x}^1 \oplus \tilde{x}^2 \oplus \dots \oplus \tilde{x}^k) \quad (4)$$

Assuming that each element of the fuzzy total-relation matrix is shown as $\tilde{t}_{ij} = (a''_{ij}, b''_{ij}, c''_{ij})$ then we can use following formulas to calculate the value of each element.

$$[a''_{ij}] = x_a \times (I - x_a)^{-1}$$
$$[b''_{ij}] = x_b \times (I - x_b)^{-1} \quad (5)$$
$$[c''_{ij}] = x_c \times (I - x_c)^{-1}$$

Step 4: Crisp value calculation

To get the crisp value we have used the method suggested by Opricovic and Tzeng [49-50] The steps followed are:

$$a_{ij}^n = \frac{(a_{ij}^t - \min a_{ij}^t)}{\Delta_{min}^{max}} \quad (6)$$

$$b_{ij}^{n} = \frac{(b_{ij}^{t} - min\ a_{ij}^{t})}{\Delta_{min}^{max}}$$
$$c_{ij}^{n} = \frac{(c_{ij}^{t} - min\ a_{ij}^{t})}{\Delta_{min}^{max}}$$

so that

$$\Delta_{min}^{max} = \max c_{ij}^{t} - \min a_{ij}^{t}$$

In this stage we calculate the upper and lower bounds of normalized values:

$$a_{ij}^{s} = b_{ij}^{n} \Big/ (1 + b_{ij}^{n} - a_{ij}^{n})$$
$$c_{ij}^{s} = c_{ij}^{n} \Big/ (1 + c_{ij}^{n} - a_{ij}^{n}) \quad (7)$$

Then, we calculate x_{ij} according to following formula:

$$x_{ij} = \frac{[a_{ij}^{s}(1 - a_{ij}^{s}) + c_{ij}^{s} \times c_{ij}^{s}]}{[1 - a_{ij}^{s} + c_{ij}^{s}]} \quad (8)$$

Step 5: Determination of threshold level

Authors used different approaches to determine the threshold value for matrix T. One way is to calculate the average value for the elements of matrix T and then letting all values less that the threshold value to zero to make causal relation null for them.

Step 6: Generating output for diagramming causal relation

In this step, we are to find the sum of each column and each row of matrix T. The sum of rows (D) and columns (R) can be calculated as follows:

$$D = \sum_{j=1}^{n} T_{ij}$$
$$R = \sum_{i=1}^{n} T_{ij} \quad (9)$$

For analysis purposes, we need to find the values of D+R and D-R, where D+R represents the degree of importance of factor *i* in the entire system and D-R represent the net effects that factor *i* contributes to the system.

Step 7: Results interpretation

According to the diagram and tables, assess each factor based on the aspects Horizontal vector (D + R) and vertical vector (D-R).

3.Resilience strategies or factors

Strategies of highly important to manufacturers are identified by researchers as they are given below:

1. Capacity management
2. Multi sourcing
3. Demand management

4. Information sharing
5. Additional inventory holding
6. Contracting with backups
7. Risk management and disaster recovery
8. Dropping Market Feeding Strategy
9. Enlightenment of business flow complexity
10. Suppliers / facilities reinforcement

3.1. Capacity expansion strategy

At some point, businesses are able to expand the capacity to produce more of the type of goods is necessary. Capacity expansion occurred in Iran in 2009 when government decided to expand its automobile fuel refinery capacity internally. This occurrence was successful making relating system more resilient. Such successes can be observed in countries where foreign business decided not to have business with that country for some specific political reason, however. Using out-sourcing/subcontracting approach along with multi sourcing strategy makes this strategy successful at the time crises. Deif and Elmaraghy [15] proposed a model for analyzing the dynamic capacity complexity in multistage production system. Dennis and Hui [16] studied the impacts of anchoring in capacity adjustments to Work-In-Process behavior in two stage production system using system dynamics approach. Rydzak and his co-researchers [58-60] studied the impacts of resilience in production systems.

3.2. Multiple-sourcing strategy

A celebrated approach known among businesses for risk reduction is multi sourcing. Here, businesses try to have backup suppliers as well as permanent suppliers for each critical portion of their business. Namdar et al. [48] studied supply chain resilience for single and multiple sourcing in the presence of disruption risks. They found that multiple-sourcing provides a better service level than single sourcing. Sawik [65] discovered that for higher significance levels, single sourcing results in higher conditional value at risk (CVAR) than multiple-sourcing. Burke et al. [6] showed that single sourcing is suitable when demand average is low, but multiple-sourcing is helpful for high demand average. Zare Mehrjerdi and Shafiei [79] studied multiple sourcing in sustainable closed loop supply chain for Tire industry in Iran.

3.3. Demand management

In normal and disturbance free situation, management likes to fully response to their customer's demand. This makes customer one hundred percent satisfied for their on- time demand fulfillment. At the time of crises and high vulnerability of the system, this strategy can work no more. This is why management tries to manage the demand and let customers know of the situation that company is dealing with, and when the demand can be filled-in fully or partially. Zare Mehrjerdi and Lotfi [80] developed a mathematical model for sustainable closed-loop supply chain with efficiency and resilience systematic framework. The model with concentration on demand management has been applied to auto industry in Iran where demand is stochastic with predetermined uniform distribution function.

3.4. Information sharing

Sharing true information with partners both internally and externally helps managements significantly in running their business. Information has tremendous power in pumping up energy into the mind of customers and cool them off at the time of dissatisfaction. How this strategy can be employed and implemented depends on the management and the type of business that they are in. No information and closed system do not help management at the crises however. Zare Mehrjerdi and Shafiei [81] have proposed a model for CLSC using information sharing and multiple sourcing strategies.

3.5. Additional Inventory holding

Although management always tries to minimize the level of inventory to reduce overall investment needed to run the business, for system's resiliency purpose keeping additional inventory is always a must.

3.6 Contracting/subcontracting with backup suppliers and facilities:

With this strategy the producer is able to deal with disruption using its power of contracting or subcontracting with other producers to manage customer's demand. Moubed et al. [45] have proposed a robust modeling of inventory routing in collaborative reverse supply chains.

3.7. Risk management and disaster recovery

This strategy guides all producers and manufactures to know all risks that its systems is vulnerable to. For this purpose, manufacture must identify risks using approaches as well as FMEA, PFMEA. Once risks are determined and verified by engineers the process of assessment begins.

3.8. Dropping Market Feeding Strategy

This strategy helps management in responding to its customers partially as their demand level is concerned. This means that management decides to respond only a portion of demand on a weekly or monthly basis to help their customer's business narrowly flow till disturbances goes away. Many governmental owned organizations work on the basis of this strategy that is known as "dropping market feeding strategy". Week economic countries dealing with high inflation and shortage of goods employ this strategy.

3.9. Illumination of business flow complexity

With this strategy businesses are able to demonstrate the level of complexity of their business to their internal and external customer to keep them relatively satisfied with the type of response that they get from their business. This strategy allows customers to track their demand and the stage that it is at. Once customers know the level of complexity of the process that their demands go through then they can appreciate its fulfillment even if they receive it later than the time was expected.

3.10. Suppliers/facilities reinforcement

The purpose of this strategy is to minimize suppliers' vulnerability to disruption. Sawik [65] proposed a model for optimization of cost and service level in the presence of supply chain disruption risks: Single vs. multiple sourcing. Sheffi Yossi [67] studied resilient enterprise to overcoming vulnerability for competitive advantage. Torabi et al. [72] studied resilient supplier selection and order allocation under operational and disruption risks.

Table 2 lists a large number of articles dealing with systems resiliency in production industry (steel, food, auto, Tire), energy industry (biomass), and service industries (healthcare, organization, inter-organizational, communities, dynamic environment).

Table 2: Researches on systems' resiliency

	Authors	Criterion	Application area	Solution Methodology

1	Rydzak, Chlebus [58]	Application of Resilience Analysis in Production Systems – Bombardier Transportation Case Study,	Production and transportation	System dynamics
2	Rydzak at al. [60]	Resilience, production, Labor designations and Maintenance	Production and maintenance	System dynamics
3	Rydzak, and Chlebus [59].	Analysis and management of resilience in production systems.	Production system	System dynamics
4	Parsaei et al. [51]	Leanness, risk management culture, and resiliency	Steel industry	ANP, DEMATEL
5	Victoria J., Holmlund, Maria, Polsa, Pia and Naidu, Megan (2023)	Resiliency and sustainability of food system	Food industry	Computer simulation
6	Lotfi, R. and Zare Mehrjerdi, Y. [80]	Demand management, SCM	Auto industry	Meta heuristic approach
7	Zare Mehrjerdi, et al. [41]	Risk management, demand management, SCM	Auto industry	Risk analysis and Meta-heuristic approach
8	Lotfi el al. [36]	A resilience and sustainable supply chain considering VMI	Health care industry	Robust optimization
9	Zare Mehrjerdi and Shafiei [81]	Supply chain management	Tire manufacturing	e-constrained method
10	Zare Mehrjerdi and Shafiei [82]	Supply chain management	Tire manufacturing	e-constrained method
11	Salehi et al. [63, 64]	Capacity management, Risk management, demand management	Biomass energy	Fuzzy Multi criteria optimization
12	Arefi and Ardakani [5]	Sustainable supply chain management	Steel industry	DEMATEL, Simulation
13	Latsou, C., et al. [38]	Resilience design, complex manufacturing system, multi-dimensional resilience	Complex manufacturing system	Multi-objective optimization
14	N. Sahebjamnia, S. A. Torabi, and S. A. Mansouri [62]	Building organizational resilience in the face of multiple disruptions	Disaster operations management	A multi-objective mixed-integer robust possibilistic programming model
15	X. Gu, X. Jin, J. Ni, and Y. Koren [25]	Manufacturing system design for resilience	Supply chain management	System design
16	Rice J.B. and Caniato [57]	Resource identification strategy, multi-tasking workforce, extra capacity generation, paying attention to contracts	Supply chain management	Quantitative metrics
17	Ipek Kazancoglu et al. [88]	Using emerging technologies to improve the sustainability and resilience of supply chains	Supply chain	Fuzzy environment
18	Dipika Pramanik [18]	Critical nodes, responsiveness, adaptive capability,	Supply chain	AHP, TOPSIS, QFD
19	Royce Francis, Behailu Bekera [56]	A metric and frameworks for resilience analysis of engineered and infrastructure systems	Uncertainty analysis Deep uncertainty	Resilience metric, Uncertainty analysis, Deep uncertainty

20	Holling CS.[29]	Resilience and stability of ecological systems	Ecological system	Quantitative metrics
21	Fiksel, J. [21]	Sustainability and resilience metrics	Sustainability and resilience	Quantitative metrics
22	Adger WN. [1]	Social and ecological resilience	Resilience	Quantitative metrics
23	Bruneau, M. *et al.* [7]	Resilience of communities	Resilience	complementary measures of resilience
24	Comfort, et al. [11]	Complex systems in crisis	Complex systems in dynamic environment	Dynamic modeling
25	Masoud Rabbani et al. [42]	Reliable supply chain network design considering resilience strategies under risk of disruption	Proactive manner versus Reactive	Mixed integer non-linear programming model
26	Torabi et al. [72]	Resilient supplier selection and order allocation under operational and disruption risks	Supplier selection	Differential evolution algorithm
27	Wieland, A., & Wallenburg, C. M. [74]	The influence of relational competencies on supply chain resilience	Supply chain	Relational competencies
28	Rabbani et al. [54]	A hybrid robust possibilistic approach for a sustainable supply chain location-allocation network design	Reactive	Robust optimization
29	Deif, Ahmed M. and ElMaraghy, Hoda A. [15]	Modelling and analysis of dynamic capacity complexity in multistage production	Manufacturing, multi stage production	System dynamics
30	Hasani &Khosrojerdi [27]	Robust global supply chain network design under disruption and uncertainty considering resilience strategies	Robust global supply chain	Parallel Memetic algorithm
31	Fayezi, S. and Ghaderi, H. (2022) [89]	What are the mechanisms through which inter-organizational relationships contribute to supply chain resilience	Supply chain and inter organizational relationship	complex adaptive systems (CAS) theory

3.11 Research methodology

Steps followed in this article for problem solving are:

Step 1: Creation of dynamic hypothesis based upon the resilience strategies using DEMATEDL approach. These strategies are capacity management, multi sourcing, demand management, information sharing, additional inventory holding, contracting with backups, risk management and disaster recovery, dropping market feeding strategy, enlightenment of business flow complexity, and suppliers/facilities reinforcement.

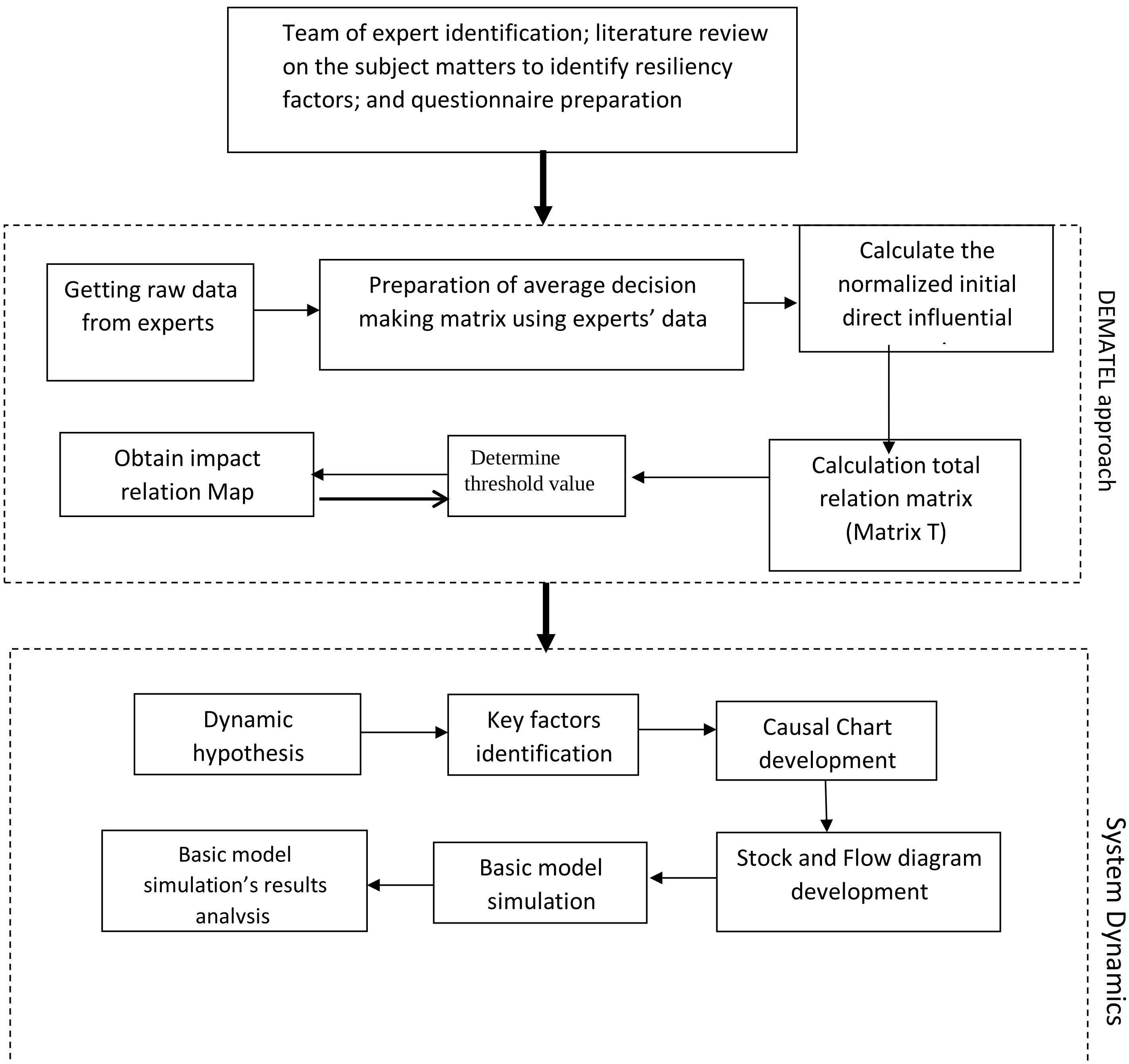
Step 2: Developing a production system with its main processes of: order rate, planned work, work in process (WIP), production rate, inventory level, desired shipment rate, backlogs, rejected rate, rework rate, required capacity, and capacity scaling.

Step 3: Expanding dynamic hypothesis using processes discussed in step 2 to generate the system dynamics of the production system for studying integrated interrelationships among desirable factors and the variables of production and resiliency, and sustainability indicators in production environment.

Step 4: Since this model presents a production system with circular resilience's strategies impacts on production scaling and hence their impacts on sustainability, indicators as such as job creation, salary, profit, investment and ecosystem are closely tracing in this production modeling.

Step 5: Best performing scenarios after completing the model simulation. This is done by getting experts' opinions about the scenarios performance to build the original decision matrix for scenario prioritization using TOPSIS approach.

Figure 1 depicts the steps followed for solving this problem. This Figure is comprised of two separate sections of DEMATEDL and System Dynamics.



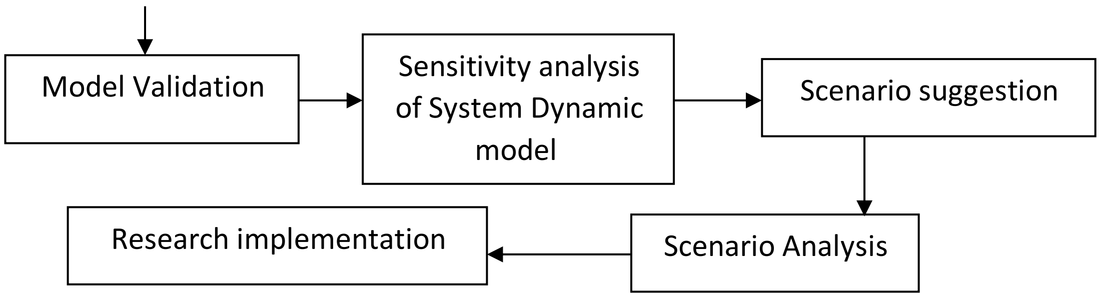


Figure 1: combined DEMATEL and System dynamics approach

4.Fuzzy DEMATEL results

Fuzzy DEMATEL approach is used to determine the dynamic of resilient factors on one another. For this purpose, a questionnaire was prepared and passed to experts in the field to complete. Ten experts participate in the study. The response of one of these experts are shown by Table 3. Five of these experts were production engineers with Master of science degrees and years of practices ranging from 10 to 16 years. Three experts were selected among industrial engineering university professor and two from management science department.

Table 3: a sample of expert's response

-	**Capacity**	**Multi sourcing**	**Contracts**	**INV Mng**	**Risk**	**Production**
Capacity	0	L	L	H	ML	VH
Multi sourcing	VH	0	L	M	H	ML
Contracts	L	L	0	H	L	VH
Inventory management	L	L	L	0	M	VH
Risk	M	MH	H	MH	0	MH
Production	L	M	M	VH	L	0

Table 4 shows the values of (Ri+Di) and (Ri-Di) while Table 5 shows benchmark level of 0.25 as it is implemented.

Table 4 shows the values of (Ri+Di) and (Ri-Di)

	Ri + Dj	Ri - Dj

Capacity	3.35	0.41
Multi sourcing	3.63	0.82
Contracts	3.29	0.24
Inventory management	4.47	-1.24
Risk	4.04	0.89
Production	4.69	-1.11

Table 5: the benchmark level based of Table T (Benchmark level=0.25)

Benchmark Level = 0.25						
	Capacity	Multi sourcing	Contracts	INV Managemen t	Risk	Production
Capacity	0.00	0.00	0.00	0.51	0.25	0.54
Multi sourcing	0.42	0.00	0.00	0.50	0.40	0.47
Contracts	0.00	0.00	0.00	0.49	0.00	0.52
Inventory management	0.00	0.00	0.00	0.00	0.00	0.49
Risk	0.00	0.35	0.41	0.57	0.00	0.57
Production	0.00	0.00	0.00	0.51	0.00	0.00

4.1 DEMATEL Causal Diagram

Using the results of Table 5, we sketched Figure 2 as casual diagram which is the basic shell of our dynamic hypothesis (DH). Taking other factors important to management in addition to what were originally considered in the questionnaire the final dynamic hypothesis was suggested to the team of our experts. After some discussions we came up with final DH shown below. Figure 3 depicts radar representation of locations of resilient factors

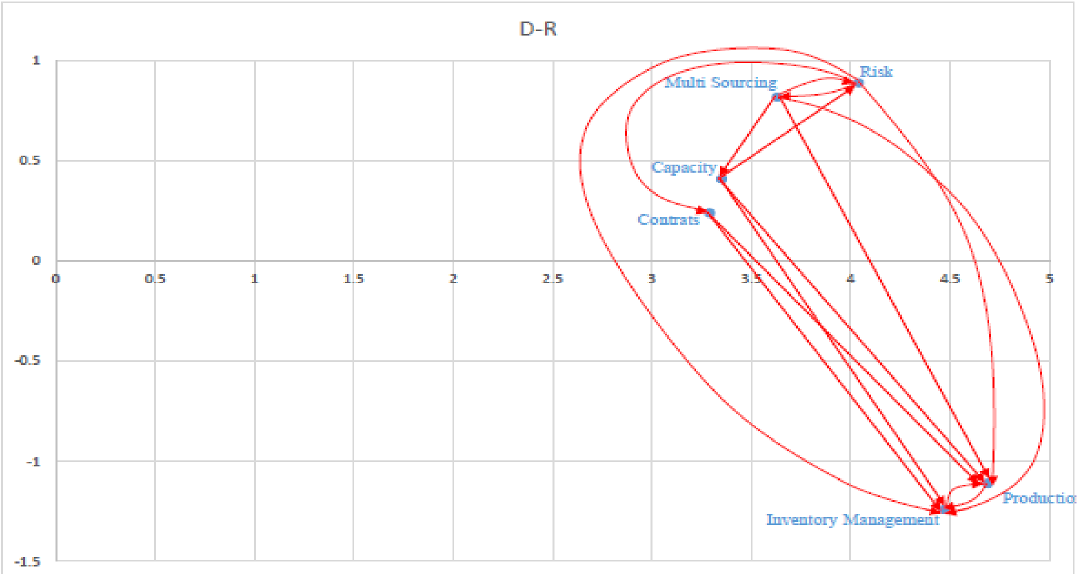


Figure 2: causal diagram extracted from DEMATEL's final calculations

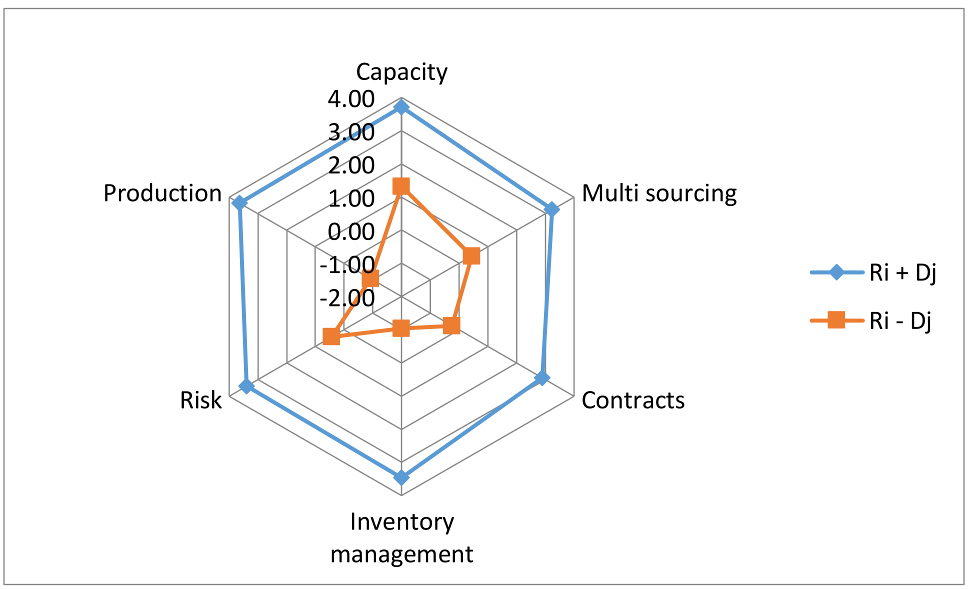


Figure 3: Radar representation of locations of resilient factors

5. System dynamics steps for problem solving

The steps to follow, as discussed by Sushil [ ] and expanded by this author, is shown by Figure 4. The solution step starts from system understanding and then follow it clock-wise step by step to problem definition, system conceptualization, simulation and validation, policy suggestion and evaluation, and policy implementation.

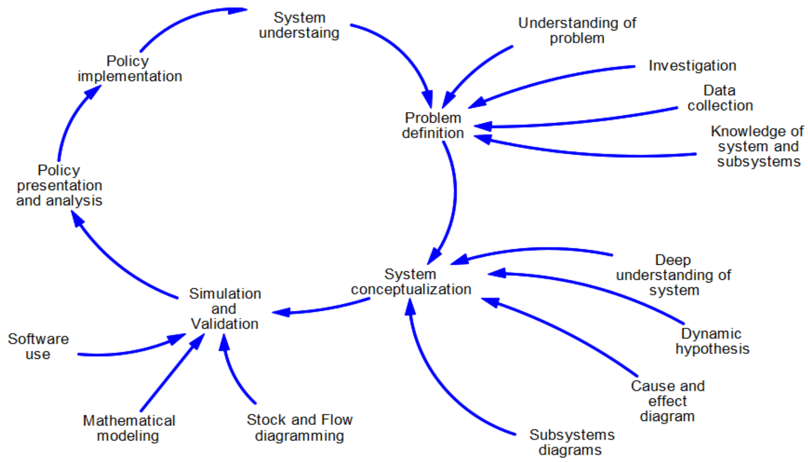


Figure 4: system dynamics steps for problem solving

5.1 System dynamics steps to model production system in resilience environment

Steps to work on the production system using system dynamics approaches are listed below:

1. True identification of production system
2. Clear description of production system
3. Determining of system states
4. Important disturbances identification for production system
5. Analysis of disturbances impact on the system
6. How improvement can be made to the production system
7. How changes can be implemented to the system

First, analysts should concentrate on the production system boundary that needs to be covered in the production model. The resources, processes, methods, and policies need to be identified. Next, a dynamic model of the production system should be built. Thereafter, we need to develop system configuration which is defined as a collection of system state variables, employed for watching certain criteria of the system, for analysis purposes.

In step 3, modeler can expand the original developed model and add new variables as needed. What disturbances may impact the production system should be answered in step 4. As stated by Felicjan Rydzak and Edward Chlebus [58], a set of disturbances constitutes a ‘disturbances scenario’. Step 5 is about deep learning of disturbances that might be shown in a model if needed. One can test the impacts of various disturbances identified into ‘Disturbances Scenarios’. Step 6 deals with the production system functionality improvement. In this stage, the interrelations between production system elements are traced and analyzed. To demonstrate the possible impacts of disturbances on the production system to peoples in the organization using a simulator of the problem makes it feasible. In the last step of the problem, one may further study the changes to the production system and developing scenarios to propose new policies to the management, however.

5.2 Resiliency dynamic hypothesis

Figure 5 depicts the resilience dynamic hypothesis of production system. Internal variables used in this dynamic hypothesis development are variables used in the DEMATEL approach. In Figure 5, some external variables are used to show that production system is under the impacts of more variables than those used in the DEMATEDL approach. Resilience paradigm can be implemented via the set of resilience capacities of absorptive capacity, adaptive capacity, and recovery. Alexopoulos et al. [87] proposed a quantitative approach to resilience in manufacturing systems. Philipp Schworm et al. [90] studied resilience optimization in manufacturing systems using quantum annealing.

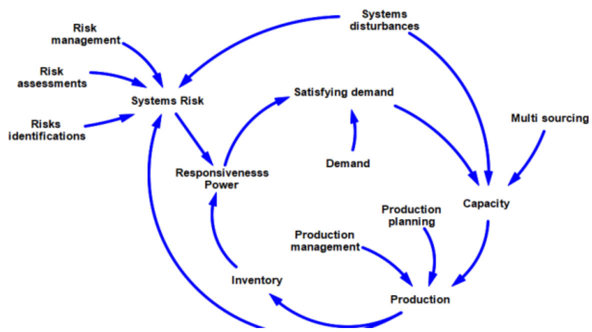


Figure 5: Resilience dynamic hypothesis

5.3 Stock and flow diagram

In system dynamics modeling, three types of variables are used to convert the concept of cause of effect diagram into a stock and flow diagram. Level variables are a type of variables that allowing accumulation occurs in that. Inventory of goods is a kind of level variable because the entrance of production of goods into the inventory causes the level of inventory to increase and when goods are sold the level of inventory decreases. What does cause the level variable to increase or decrease is the rate variable. The relations between level variable and rate variable can be shown by the following general formula:

$$\text{Level (t)} = \text{Level (t-1)} + DT * \text{Rate (t-1, t)} \quad (10)$$

This means that

$$\text{Rate (t-1, t)} = \text{Changes in Level variable} / DT \quad (11)$$

The third type of variable that is known as auxiliary variable being used for better modeling description to provide more understanding of the concepts. Parameters and constants are also allowed to be used in the mathematical modeling of the problem and hence in simulation. Figure 12 is a representation of sock and flow diagram for production where rectangular are used for Level variables identification and Rate (t-1, t) or RT is used for rate variable.

6.Production control under the dynamics of resilience factors

The variables used for this model building are shown in Table 6. Now, the model is more comprehensive than any of the previous two models. In this model, resilience factors of multi sourcing, capacity (new capacity), Vulnerability, and disturbances are considered. Additionally, the impacts of resilient production system on sustainability indicators of Jobs, Salary and Ecosystem are studied by periods. This S&F diagram depicts 14 level variables and 22 rate variables which are used to showing the positive and negative impacts of rate variables on level variables. Two rate variables show the impacts of multi sourcing for subcontracting purposes. One subcontractor source provides 35% required backlog and other contractor provides 65% to help us to response our customers. The subcontracting contracts are presented through the proposed numbers of 0.35 and 0.65 for suppliers, respectively.

Table 6: Indigenous variable and exogenous variables used in production model

Indigenous variable	Exogenous variables	Other variables
ProRT (Production rate), INV, SRT (Sales rate), Total sale, IncRT (Income rate), Total Income, ProfRT (Profit rate), Total profit, InvestRT (investment rate), Total investment, CapRT (Capacity rate), Capacity, Capout, Artificial variable, JobRT (Job rate), Jobs, JobOut, Salary RT (salary rate), Salary, salary Out, EcoRT (Ecosystem rate), Ecosystem, EcoOut. Production order rates, planned work, production started rate, product in production, production rate, reject rate, rework in process, rework rate, ready production, ready production rate, Inventory, Delivery, delivery rate, expected order fulfillment rate, backlog, pressure from management, wages and salaries, employee safety, Multi sourcing, wages and salaries, employee safety, competitors, Workforce, Contracts	Production unit, demand, unit price, Marginal profit, Marginal investment, CapFactor, Vulnerability, Disturbances Customer demand, feasible production rate from employees, feasible production rate from infrastructure, inventory policy for demand fulfillment	Workforce, employee safety, competitors, good quality, after sales services, delay, production management, customer satisfaction

(i)Backorder

Backorder (t) = Backorder (t-1) +DT * (Inflow –Outflow)
Inflow = Order (t) = Demand (t)
Outflow = Shipment-Rate (t)
Shipment-Rate (t) = Minimum (Desired-Shipment-Rate, Maximum-Shipment-Rate)
Desired-Shipment-Rate (t) = Backorder (t) / Target-Representation-Time

(ii) Capacity and Inventory

Required-Capacity (t) = Adjusted-Inventory (t)
Adjusted-Inventory (t) = {Desired-Inventory-Level – Current-Inventory-Level) /Adjustment-time-for-Inventory)}
Inventory (t) = Inventory (t-1) + DT * (Production-Rate –Shipment-Rate)
Desired-Inventory-Level (t) = Demand (t) – Desired-Inventory-coverage (t)
Desired-Inventory-Coverage =Minimum-order-processing-time + Safety-stock-coverage
Maximum-Delivery-Rate (t) = Inventory (t) /Minimum order processing time
Capacity (t) = Capacity (t-1) + DT * Scaling Rate (t)

Scaling Rate (t) = {(Required capacity (t) + Newly-developed-Capacity (t) –Capacity (t)) * SI (t)} / SDT
Scalability-Delay-Time (SDT) = 2
Required Capacity (t) = {Wp * Production-Starting-Rate (t) + Wi * Adjusted-Inventory (t) + (1-Wp – Wi) * Product-in-Production (t) /Manufacturing-Lead-Time}*Manufacturing-Unit-Time
0<= Wp <=1, Wp + Wi <= 1
Manufacturing-Unit-Time = 1

(iii) Resiliency

New capacity development relates to the money associated with investment for expansion. This investment is a function of profit made from the sales of products. Hence, following formulas are used for this purpose.

Income = Unit price * Total Sales
Profit =Profit margin * Income
Investment = Investment Margin * Profit
Disturbances = Factor * Vulnerability
Vulnerability=Tested for values between {0.10 through 0.99}
Factor = a predefined value

(iv) Sustainability

Three indicators of Jobs, Salary (t) and Ecosystem (t) are traced using appropriate formula. These indicators are used for tracking the social dimension, the economic dimension, and environmental dimensions using Salary, Jobs, and ecosystem performance over the time, respectively.

Jobs (t) = Jobs (t-1) + DT * (JobsIn – JobsOut)
Salary (t) = Salary (t-1) +DT * (SalaryIn – SalaryOut)
Ecosystem (t) =Ecosystem (t-1) + DT* (EcosysIn - EcosysOut)

(v) Rework

Rework-In-process (t) = Rework-in-process (t-1) + DT * (Reject-rate – Rework-rate)
Reject-Rate = Constant * Production-Rate
Rework-Rate = Reject-Rate / Reworking-Employees
Reworking-employee=N

(vi) Customer Satisfaction

Customer satisfaction is a function of price, quality, reliability, after sale services, guarantee, on time fulfillment of demand, delay, and lead time. However, in this study we considered satisfaction to be a function of demand fulfillment as described in the following formula.

Satisfaction (t) = Satisfaction (t-1) + DT* {Demand-Fulfillment /Customer-Demand}

Average Satisfaction= Satisfaction (t=N) / N
N = number of periods used in simulation study

Required capacity

Required capacity is a function of production start time, work in process, inventory, and other variables used in Figure 6. The formula used to calculate that is as shown in section 6. Required capacity has a structural format in accordance with Figure 6. Figure 7 shows the impacts of variables on required capacity as Vensim computer software uses in its production simulation modeling.

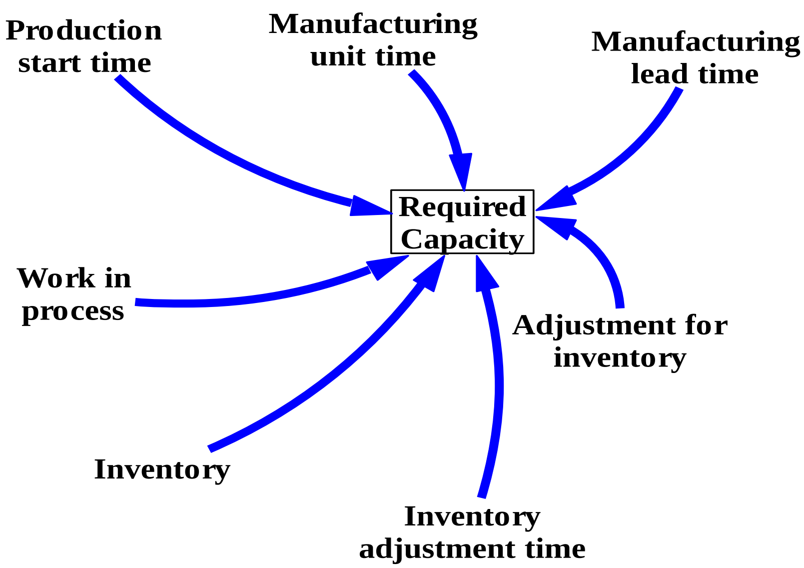


Figure 6: schematic view of required capacity

Required Capacity (t) = {Wp * Production-Starting-Rate (t) + Wi * Adjusted-Inventory (t) + (1- Wp – Wi) * Product-in-Production (t) / Manufacturing-Lead-Time}
0<= Wp <=1, Wp + Wi <= 1

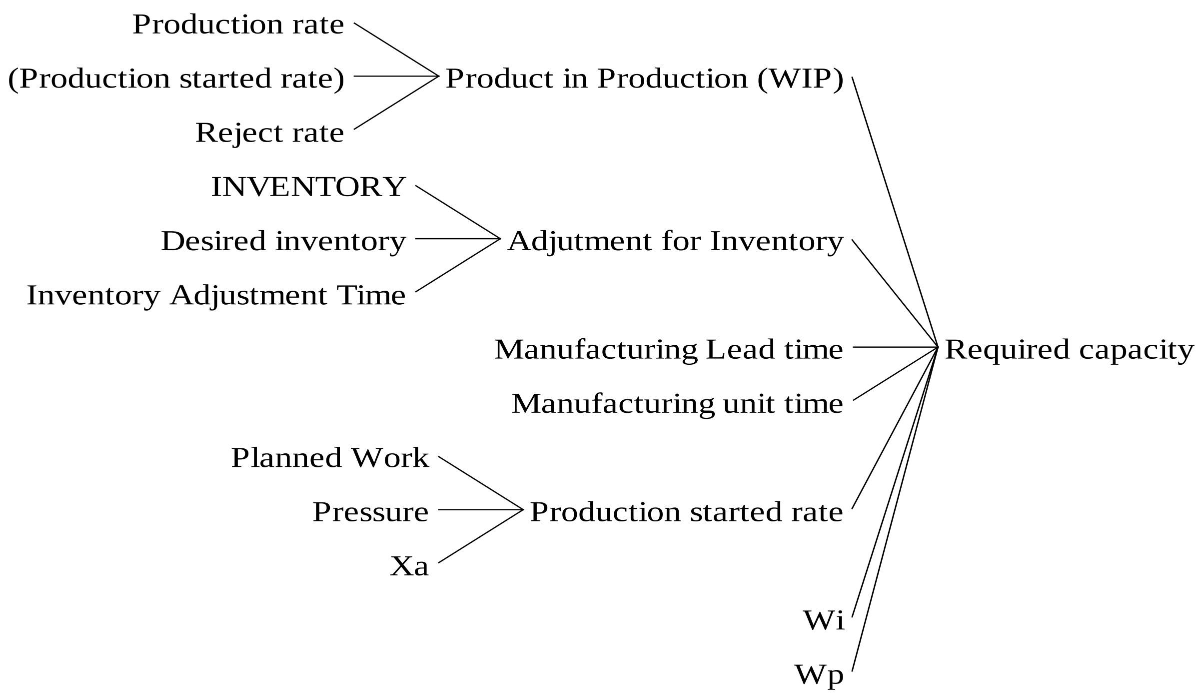


Figure 7: Schematic view of required capacity using impacting variables

Scaled Capacity

Capacity is a function of required capacity and scaling delay and other variables used in Figure 8 below. The formula used to calculate capacity is as shown in section 6 above. Scaling rate has a causal structure as given by Figure 9 in Vensim computer software.

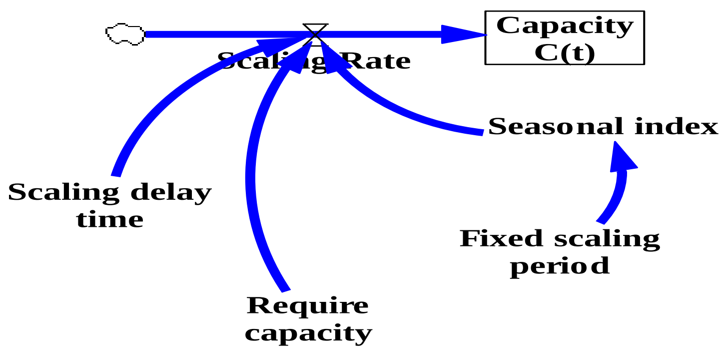


Figure 8: schematic view of newly developed capacity

Capacity (t) = Capacity (t-1) + DT * Scaling Rate (t)

Scaling Rate (t) = {(Required capacity (t) + Newly-developed-Capacity (t) –Capacity (t)) * SI (t)} / SDT

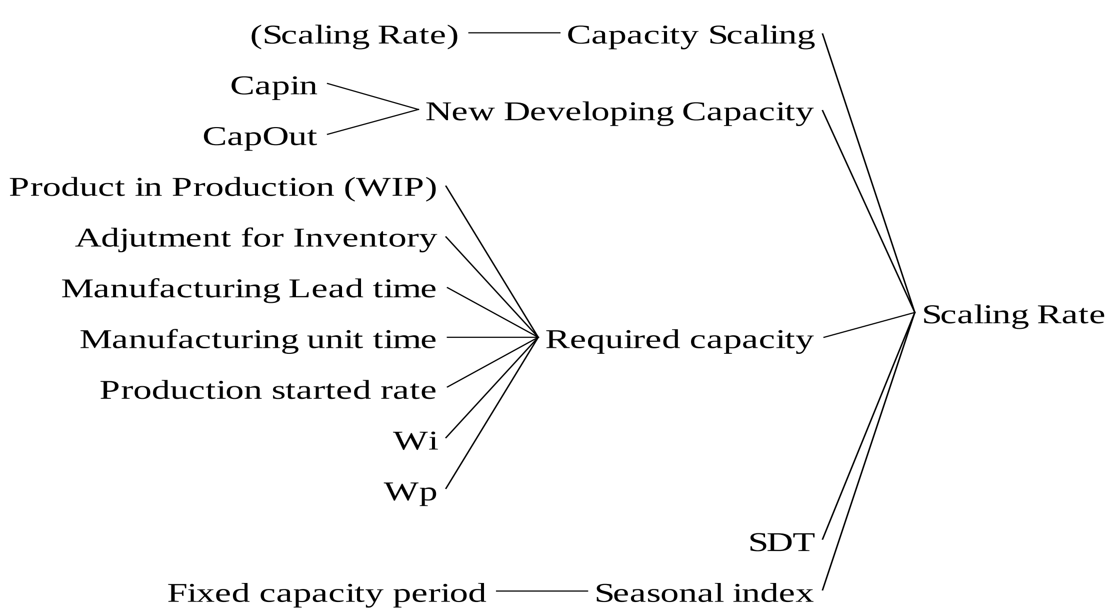


Figure 9: schematic view of scaling rate used for capacity scaling

Chain concept

Production rate is a function of capacity, utilization, manufacturing unit time and more. Figure 10 shows the chain of WIP, production rate, inventory, sales rate, and total sale as Vensim simulation model uses.

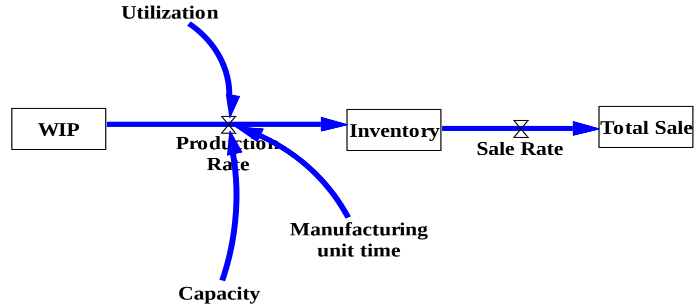


Figure 10: schematic view of inventory and total sale

Desired inventory

It is a function of inventory and desired inventory coverage as presented by Figure 11. We can calculate desired inventory value according to following formula.

Desired-Inventory-Level (t) = Demand (t) – Desired-Inventory-coverage (t)

Desired-Inventory-Coverage =Minimum-order-processing-time + Safety-stock-coverage

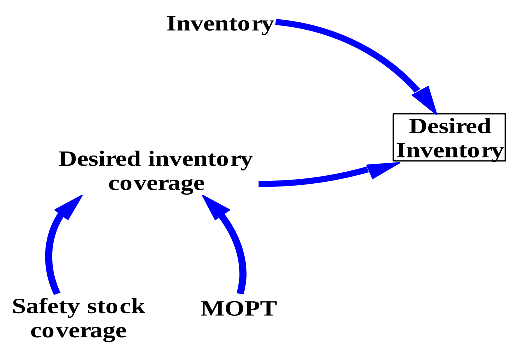


Figure 11: schematic view of desired inventory

The model solved is based upon the assumptions given below.
Vulnerability =0.2
Demand is uniformly distributed such that Demand = U (180, 200)
Manufacturing unit time =2
Target responsive time =1
Minimum order Processing time (MOPT) =1
Safety stock coverage = 120

Table 7: results based on vulnerability degree

Vulnerability	New Capacity Development	Backlogs
0.1	89	55

0.2	67	45
0.5	37	36
0.7	28	41
0.9	23	125
0.99	21	458

Table 8: results based on vulnerability degree

Vulnerability	Work in Process	Rework in process	PRD	DEL	Backlog	New Developing Capacity
0.20	202	36	213	199	45	67
0.50	196	33	207	199	36	37
0.90	196	33	176	177	125	24

Figure 12 shows the trends of planned work, production order rates, production started rate, production rate, ready products, PRD (production rate send to inventory), inventory, and delivery rate (DEL).

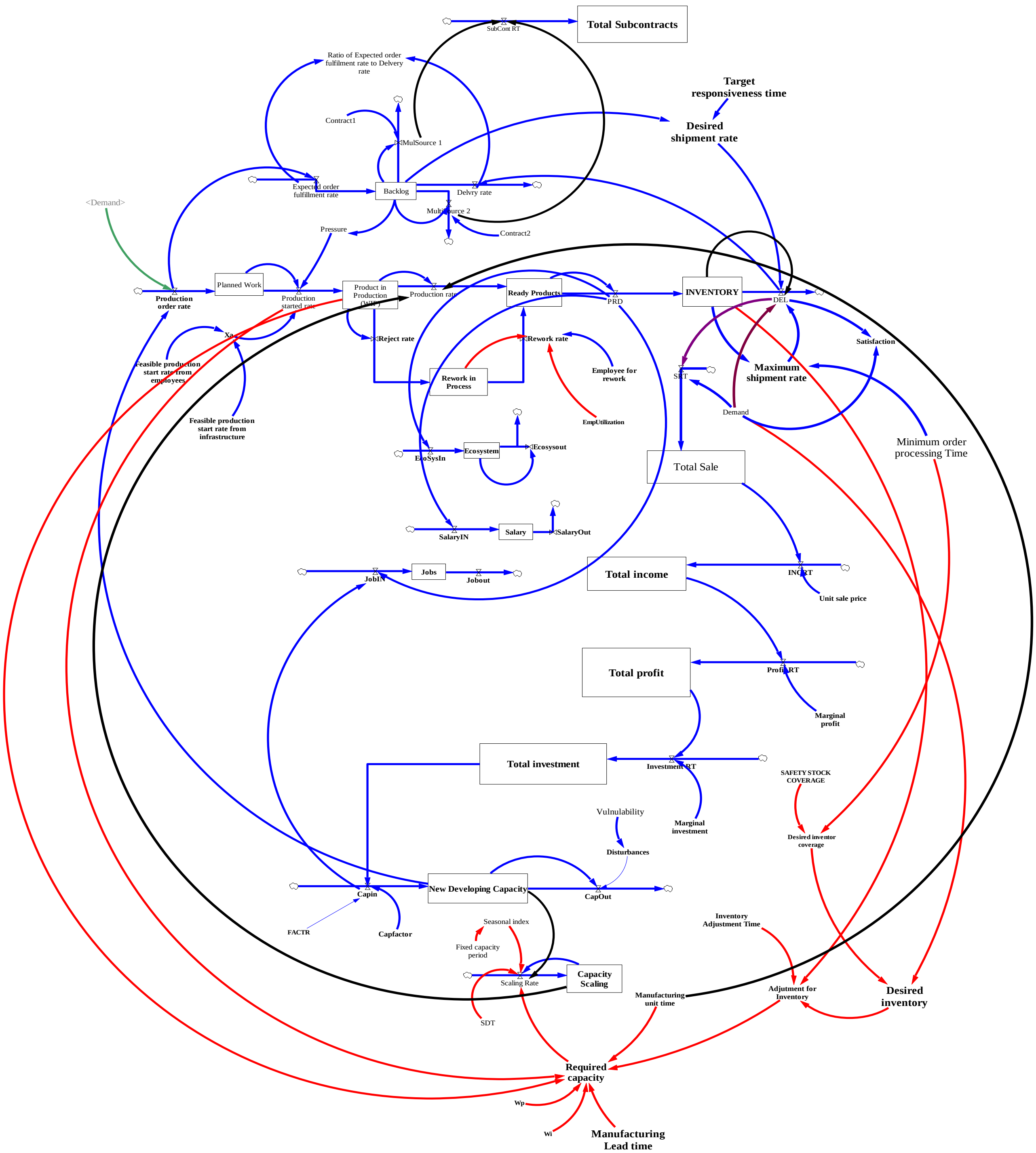


Figure 12: Stock and flow diagram of production system with capacity scaling

7.Simulation results presentation and discussion

Figure 13 shows the trends of variables product in production (WIP), DEL, inventory, production rate, ready products, and rework in process for 60 durations. Figure 14 shows the trends of DEL, PRD, and production rate for 60 durations.

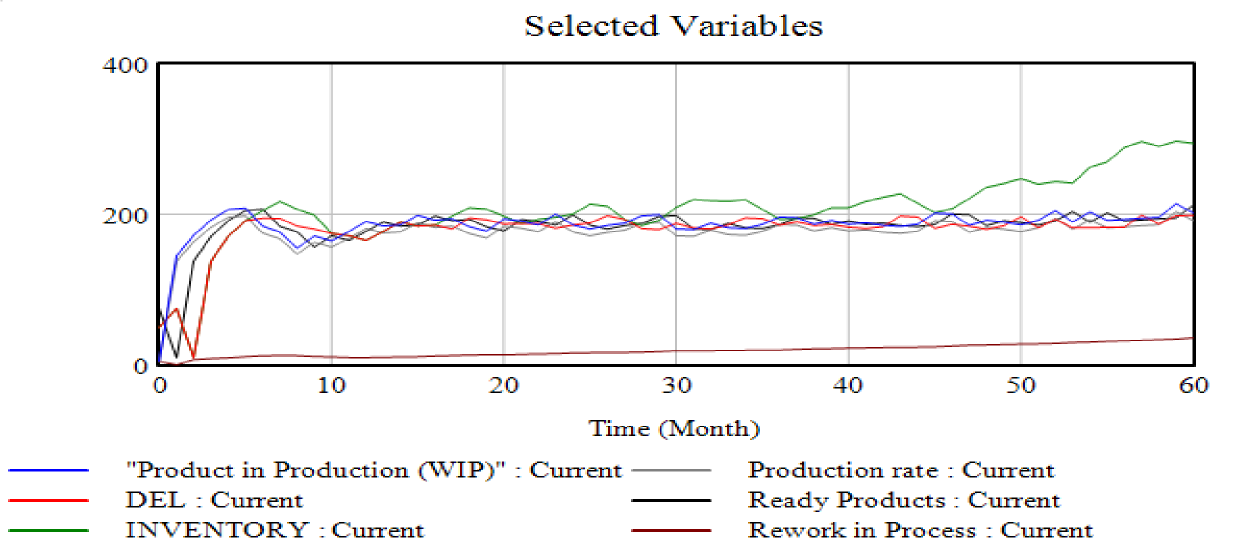


Figure 13: comparison of product in production, DEL, Inventory, production rate, ready products, and rework in process

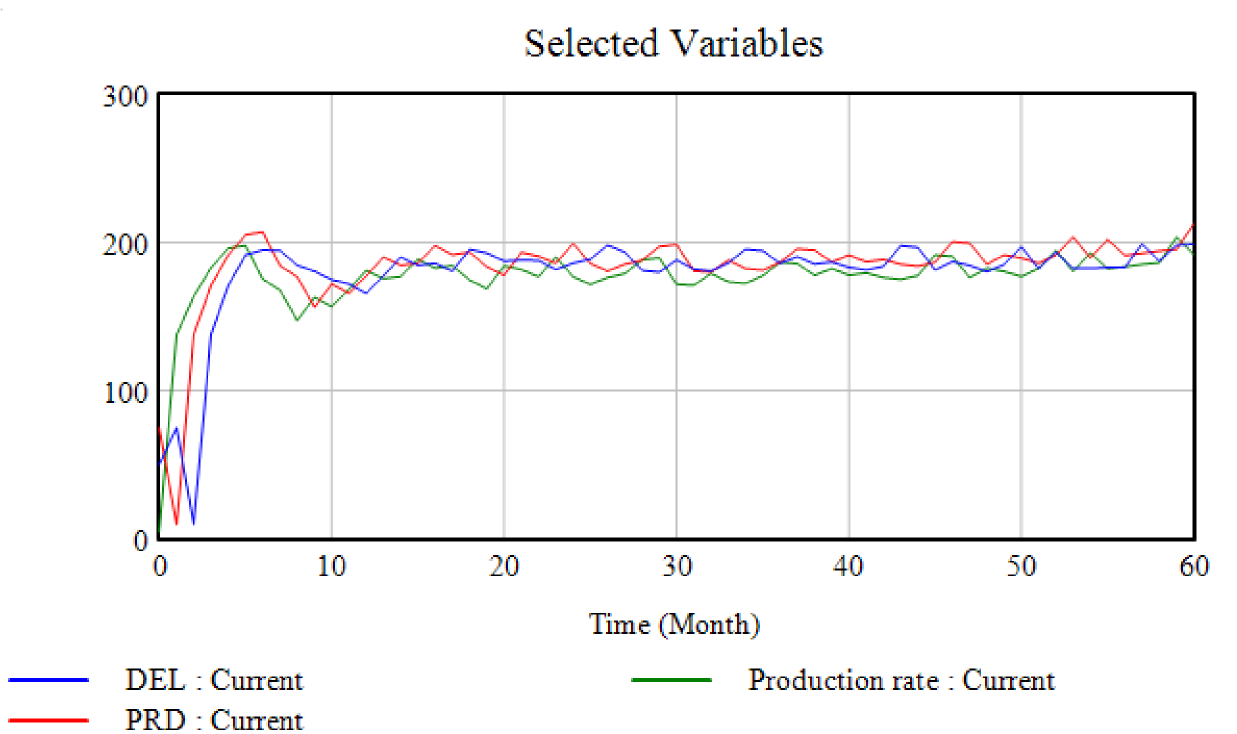


Figure 14: **comparison of DEL, PRD and production rate**

Figure 15 shows the trends for DEL, desired shipment rate, expected order fulfillment rate, and the trends of services by the multi sources of 1 and 2. Since contract mode with suppliers are a function of backlogs therefore lines for Multi Sources 1 and 2 staying close to each other as expected. The blue trend line indicates the backlog and the red line is the delivery made to customers. Figure 16 shows a schematic view of WIP, production rate, ready products, Rework-in-process. Reject-rate, and Rework rate

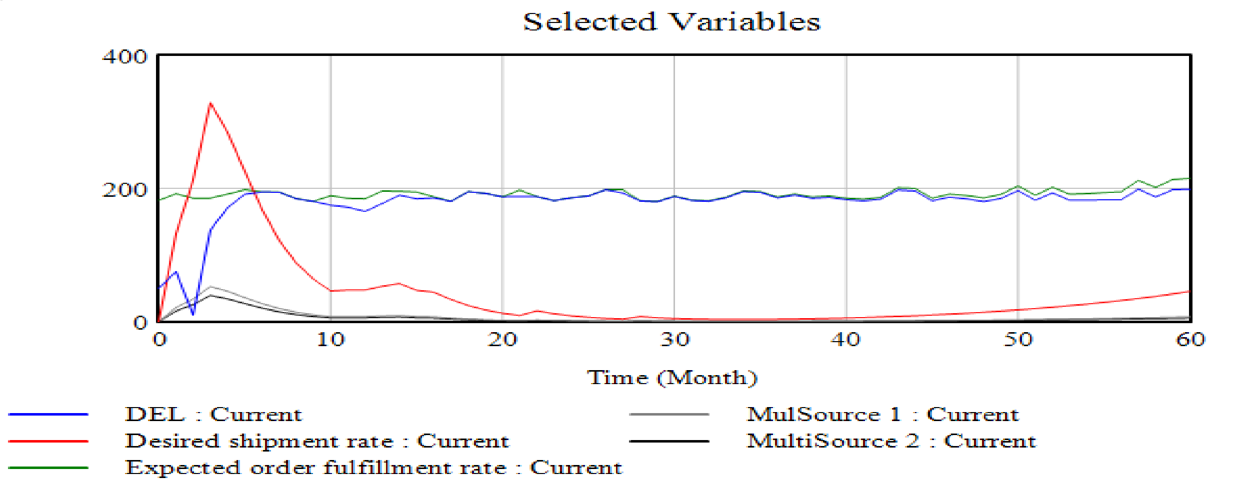


Figure 15: schematic view of DEL, Desired shipment rate, expected order fulfillment rate, and contract rates with suppliers 1 and 2

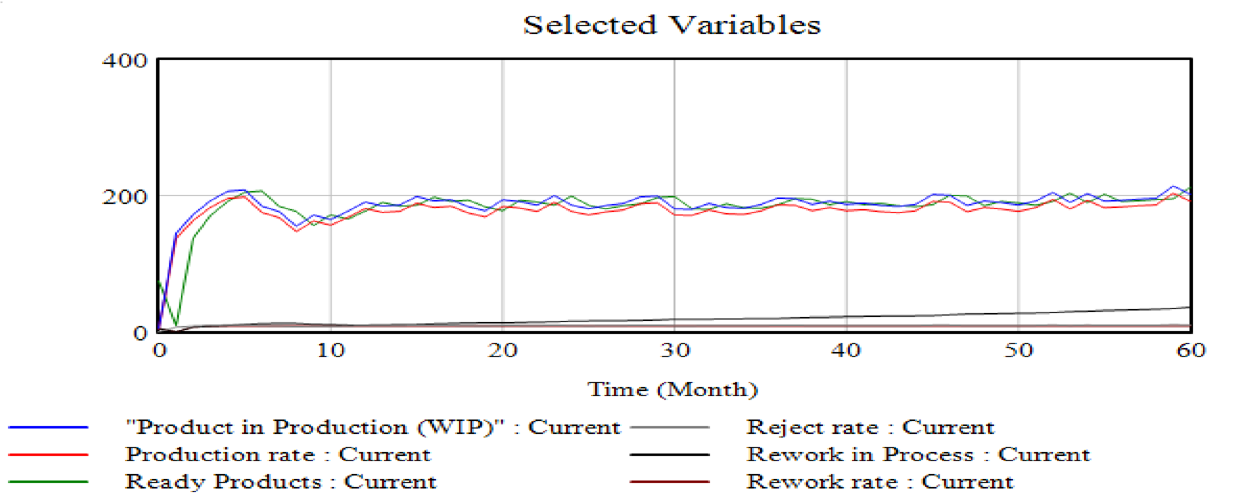


Figure 16: schematic view of WIP, production rate, ready products, Rework-in-process. Reject-rate and Rework rate

Figure 17 shows the trends for Capin (capacity generation rate), Jobs created, salary trend, and ecosystem behavior. In all situations, the trends is up-warding and doing well. The blue line, green line and brown line show the trend for ecosystem, salary, and jobs, respectively. Figure 18 is a schematic view of delivery (DEL) and demand. As figure shows these variables are very close to each as time passes.

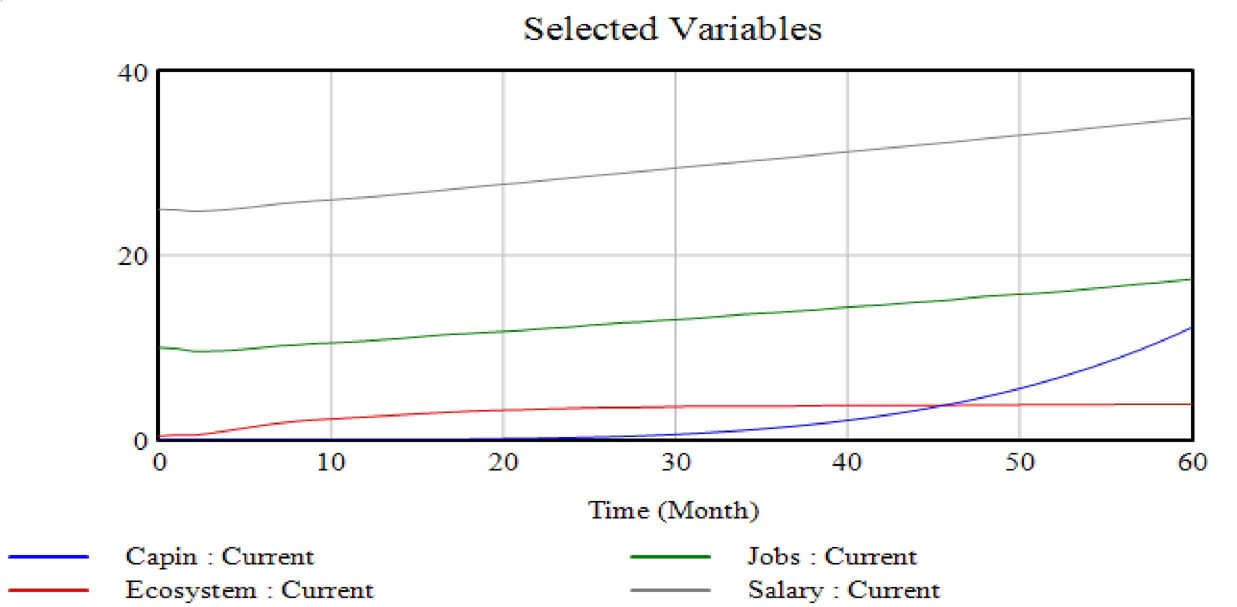


Figure 17: schematic view of capacity generation rate (Capin), Ecosystem, Jobs, and salary behaviors over 60 periods

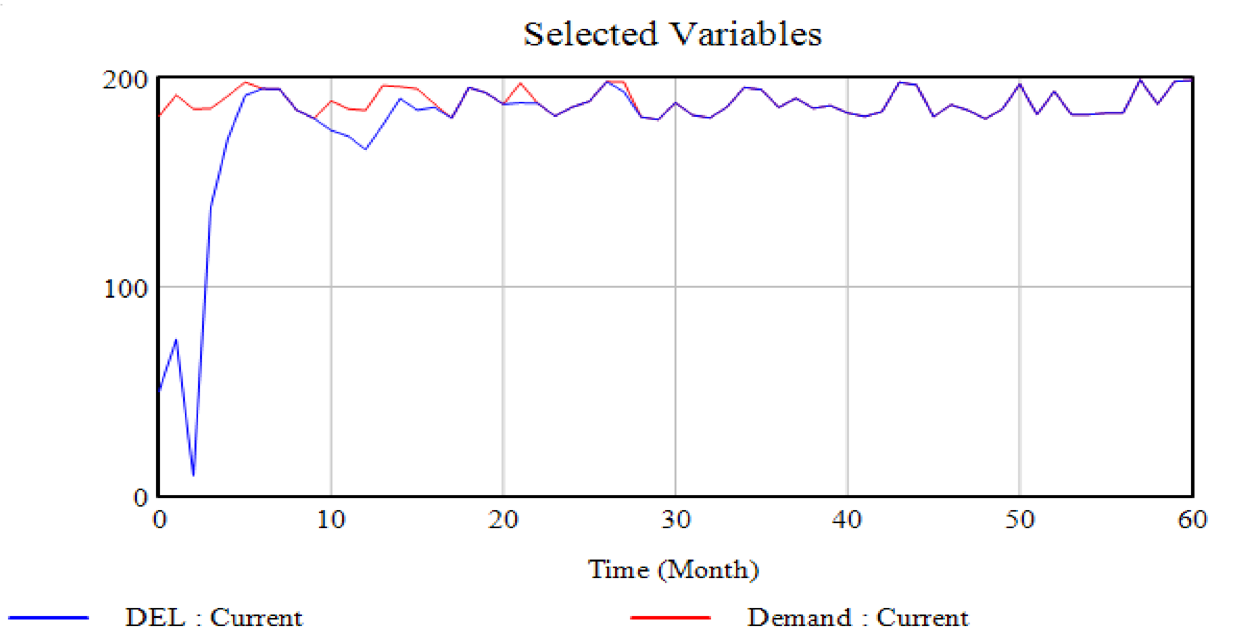


Figure 18: schematic views of Del and Demand

Figure 19 shows the trend of variables DEL, Demand, INVENTORY, and PRD. Figure 20 shows the trends of customer's satisfaction as a function of DEL and Demand. Although customer satisfaction has up and down trend, its lowest value is 0.59 and highest value is about 0.75. The formula for satisfaction can be changed as management desires or business enforce to do.

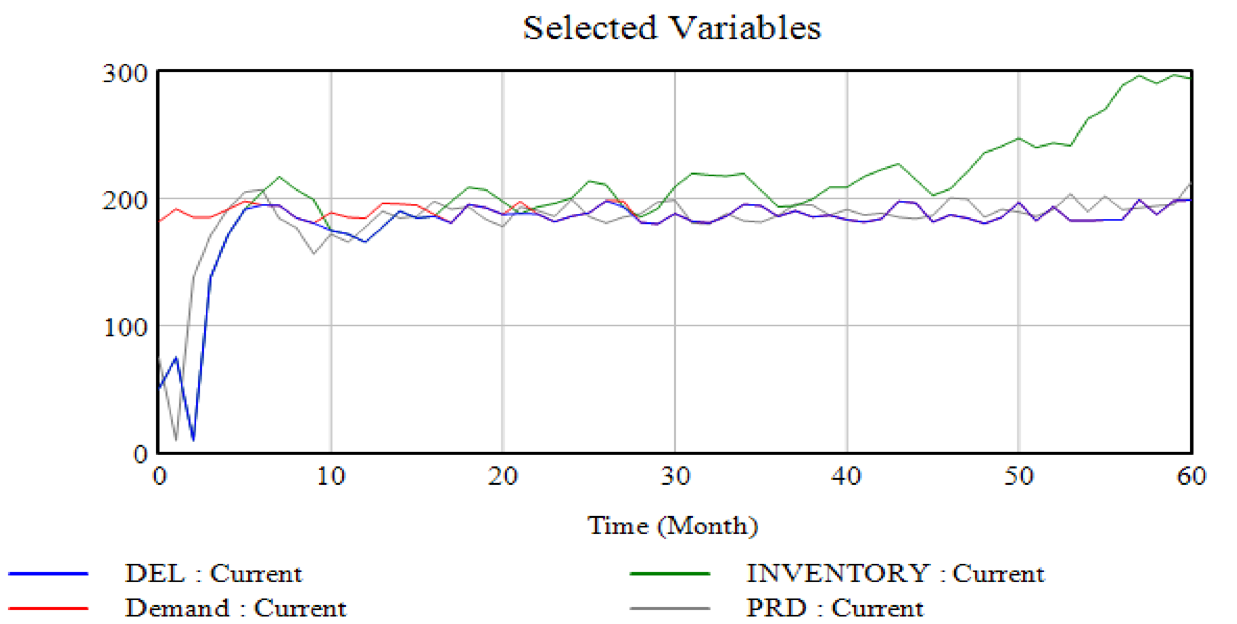


Figure 19: schematic views of DEL, Demand, INVENTORY, and PRD

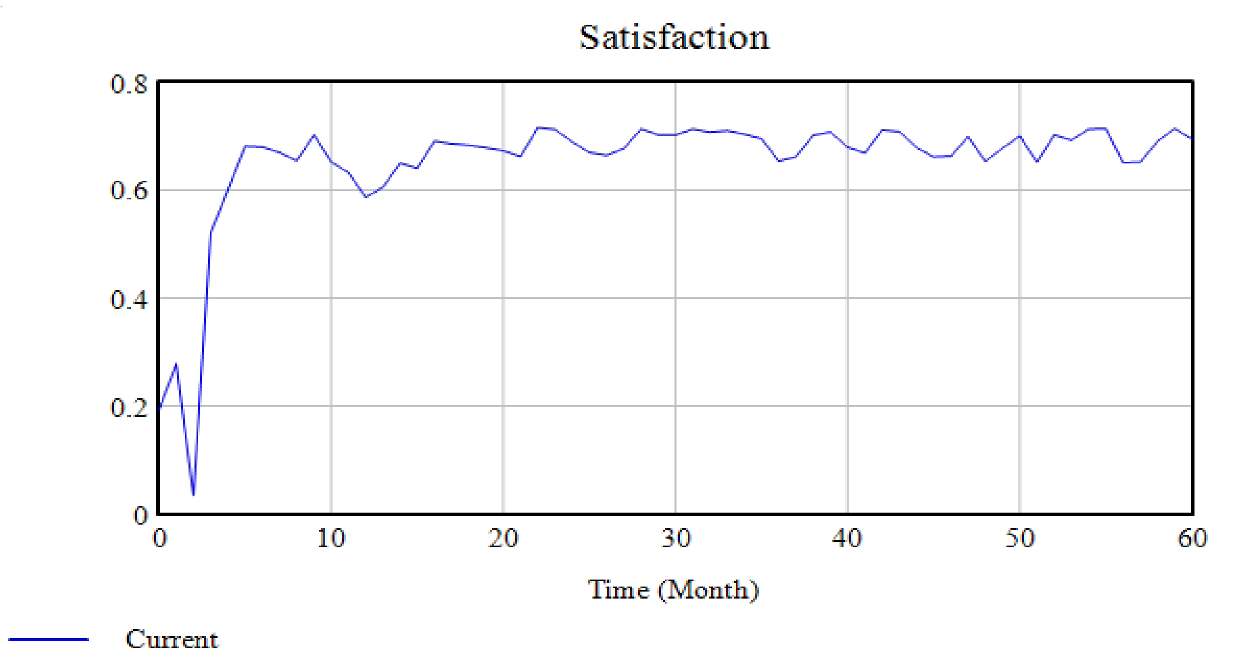


Figure 20: schematic view of satisfaction as a function of DEL and Demand

Figure 21 shows the trends of demand, profit rate, income rate (INCRT), total income, total investment, total profit and total sale. Since income rate is considered to be a direct function of total sale the new developing capacity is increasing. Figure 22 shows trends of demand and PRD. Figure 23 shows a view of demand, PRD, DEL, Desired shipment rate, and Maximum shipment rate

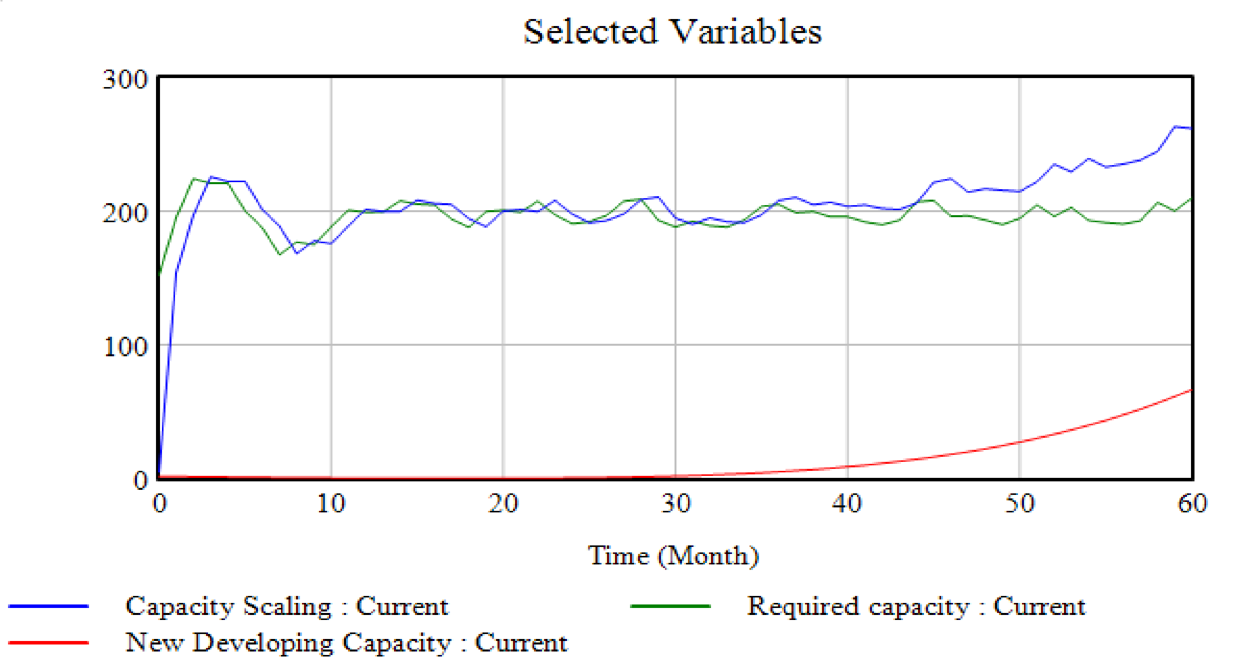


Figure 21: schematic view of Capacity, new developing capacity, and required capacity

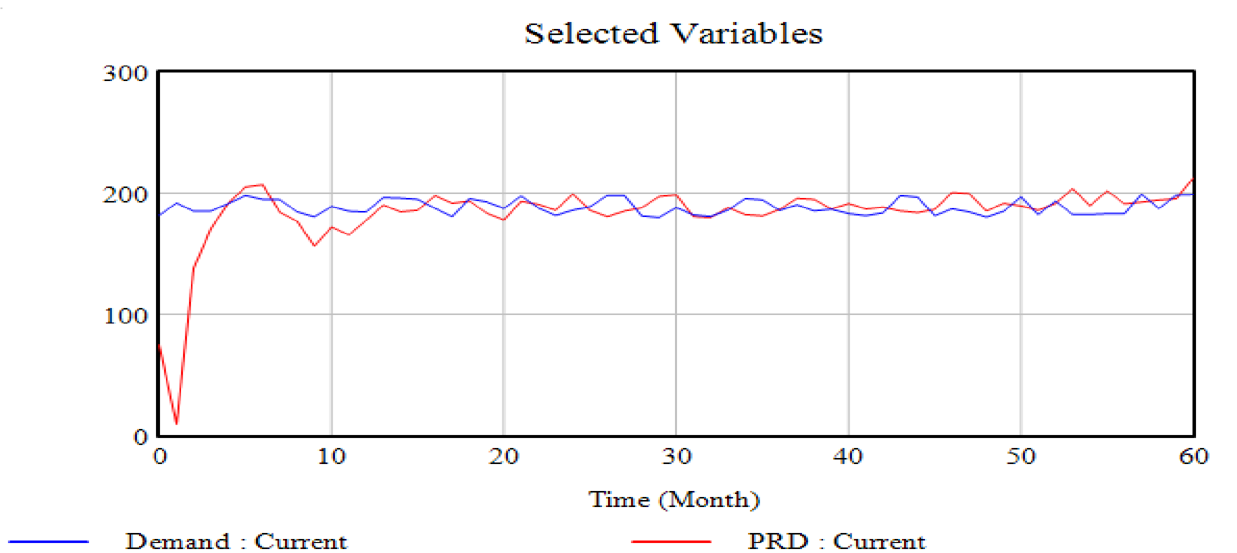


Figure 22: schematic view of demand and PRD

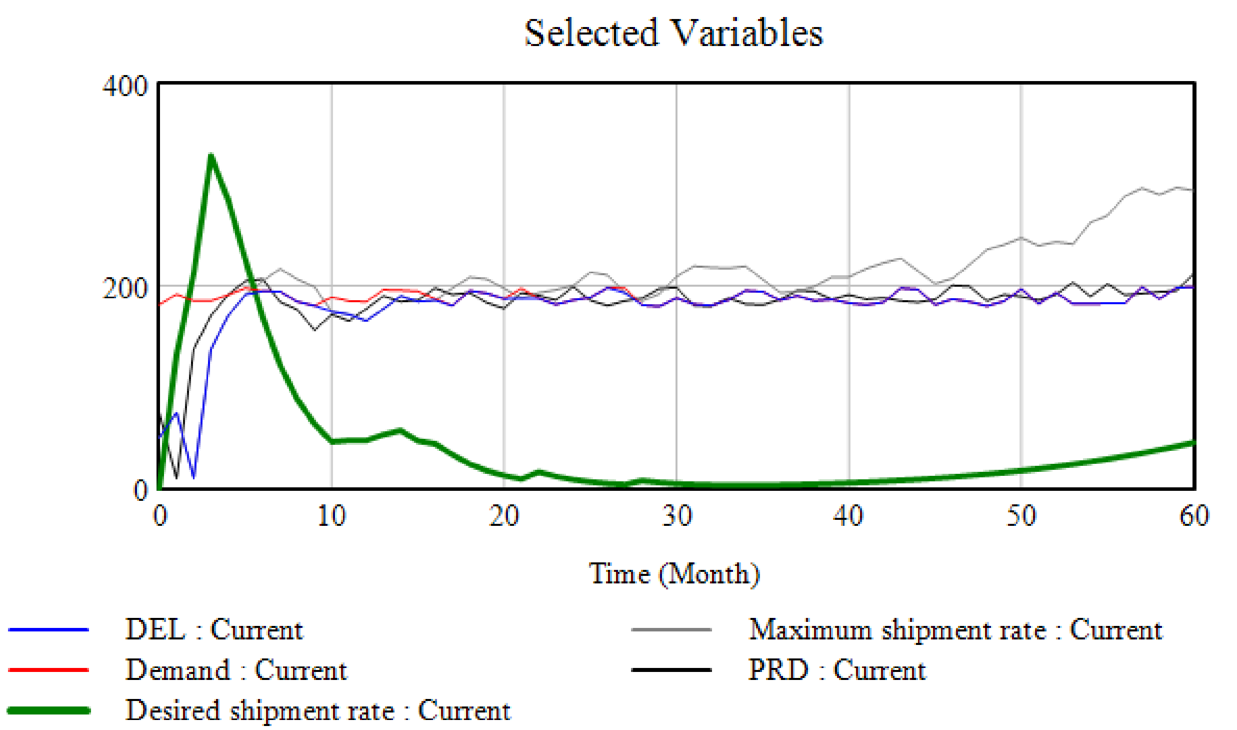


Figure 23: schematic view of demand, PRD, DEL, Desired shipment rate, and Maximum shipment rate

8.Production sustainability Indicators

The production model proposed in this article considers rework in process as a variable. Reject rate and rework rates are used as inflow and outflow for the rework in process variable. Figures 24, 25 and 26 show the trends of indicators for three pillars of: social (jobs), economic (Salary), and ecosystem situation (ecosystem), respectively.

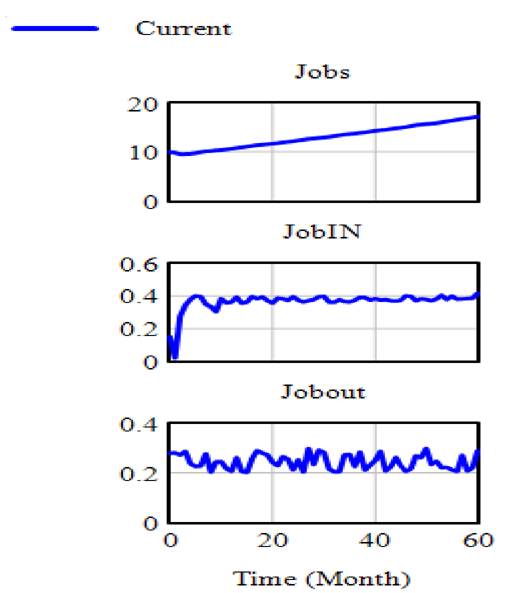


Figure 24: Jobs creation as economic indicator

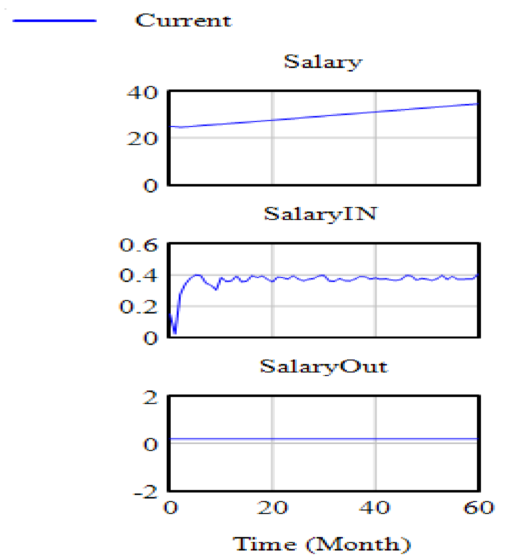


Figure 25: Salary pay as social indicator

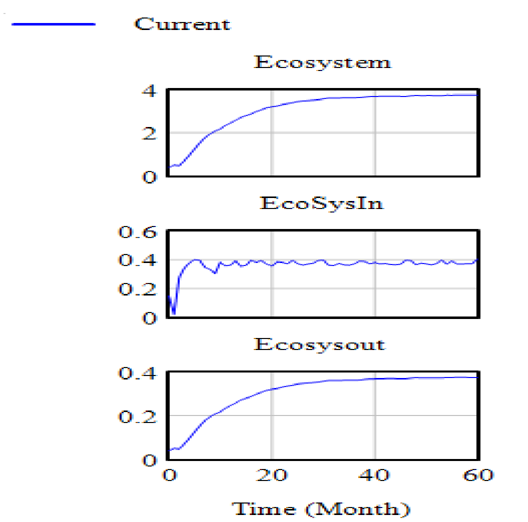


Figure 26: ecosystem behavior as environmental indicator

9.Capacity Scaling results

Result of this section relates to the capacity scaling taking wi and wp values into consideration. Figure 27 compares trends of capacity scaling, required capacity, and scaling rate in a normal manner of modeling. Figure 28 shows trends of INVENTORY and required capacity when Wi=Wp=0. Figure 29 compares trends of INVENTORY and required capacity when Wi=Wp=0.5. Figure 30 compares trends of INVENTORY and required capacity when Wi=1 and Wp=0. Figure 31 compares trends of INVENTORY and required capacity when Wi=0 and Wp=1. Figure 32 compares trends of INVENTORY and required capacity when Wi=0.35 and Wp=0.4

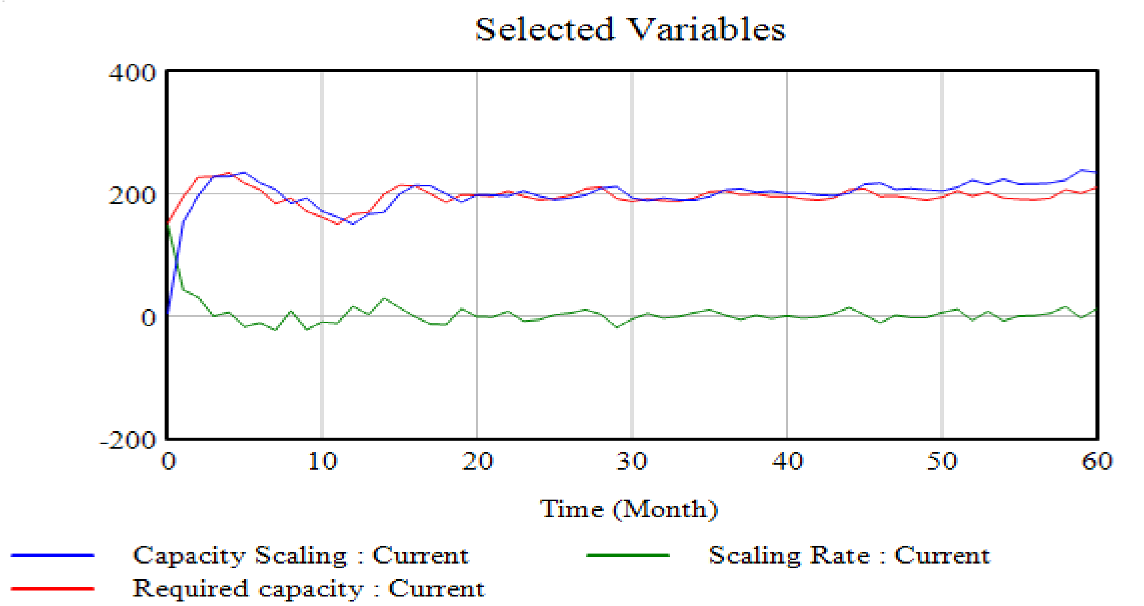


Figure 27: Comparing trends of capacity scaling, required capacity and scaling rate

Figure 28 compares trends of INVENTORY and required capacity when Wi=Wp=0.

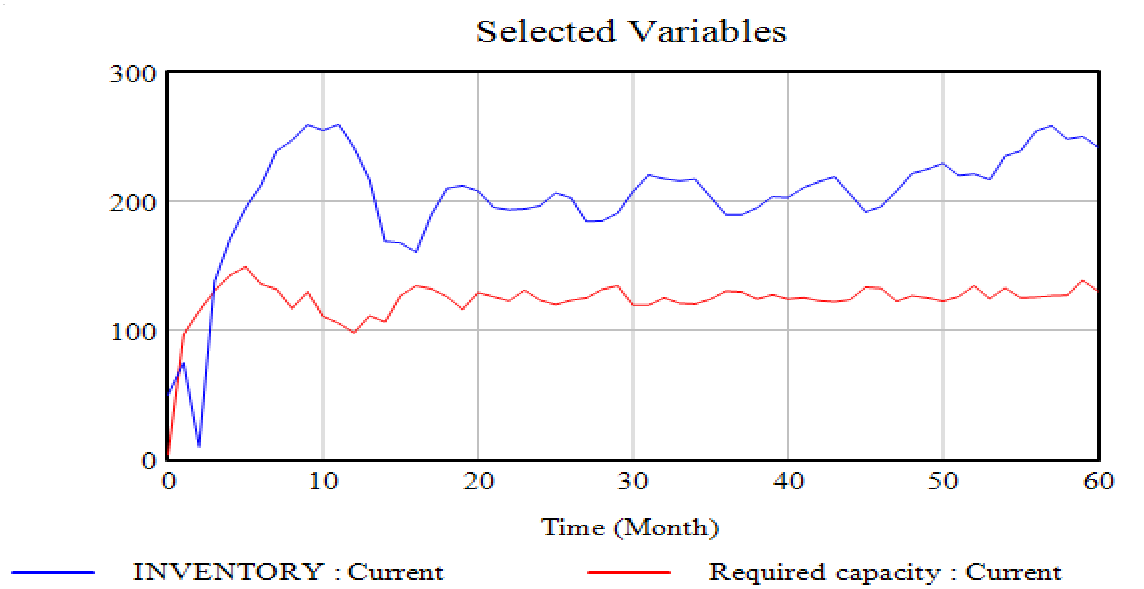


Figure 28: Comparing trends of INEVENTORY and required capacity

Figure 29 compares trends of INVENTORY and required capacity when Wi=Wp=0.5

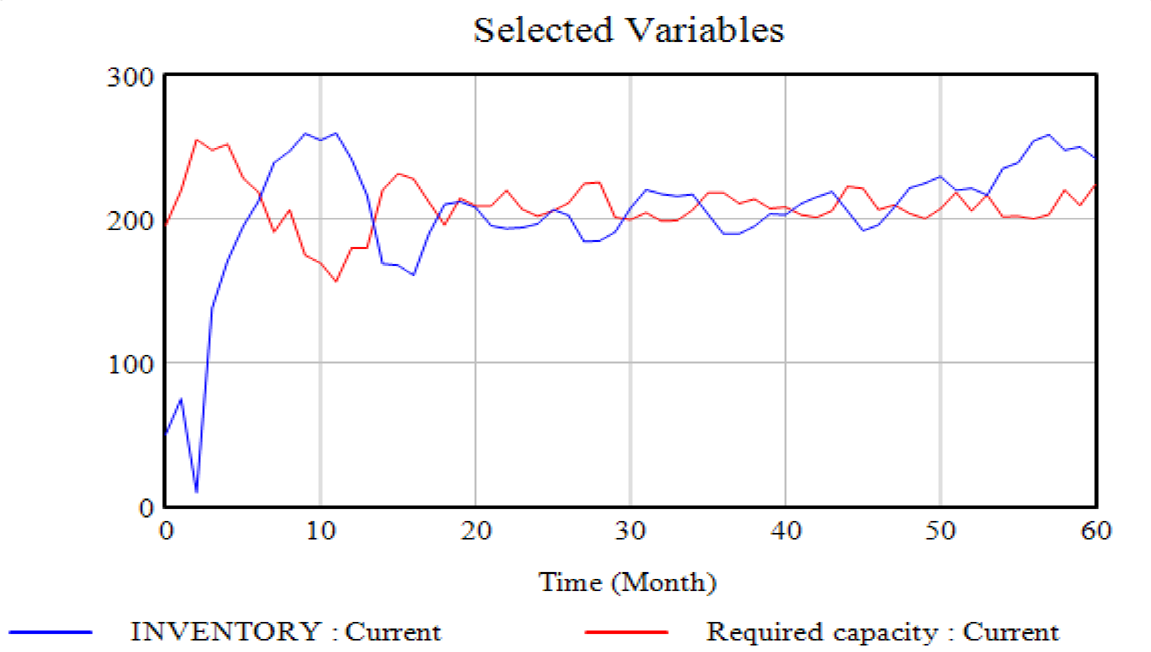


Figure 29: Comparing trends of INEVENTORY and required capacity

Figure 30 compares trends of INVENTORY and required capacity when Wi=1 and Wp=0

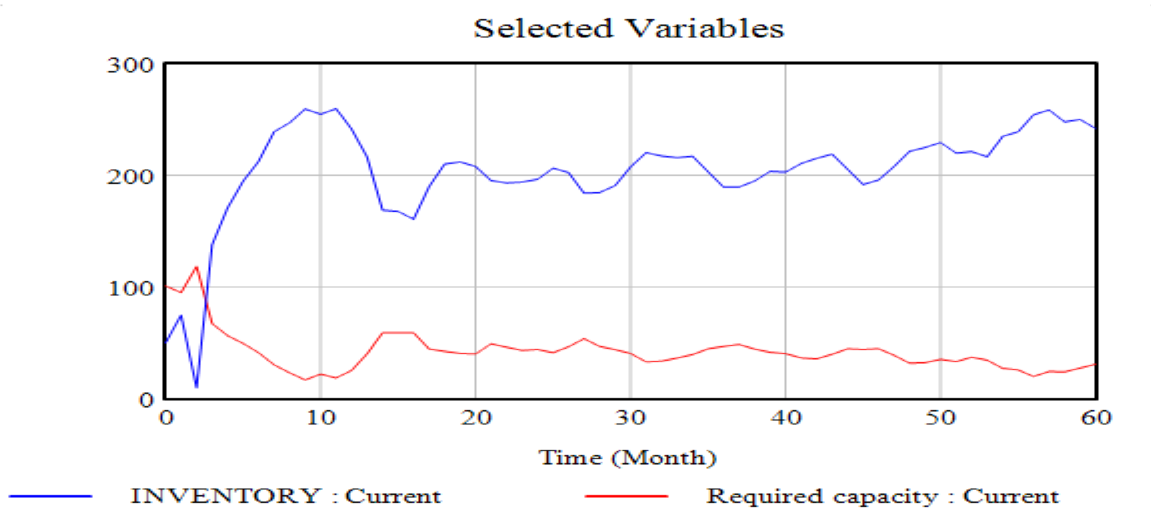


Figure 30: Comparing trends of INEVENTORY and required capacity

Figure 31 compares trends of INVENTORY and required capacity when Wi=0 and Wp=1.

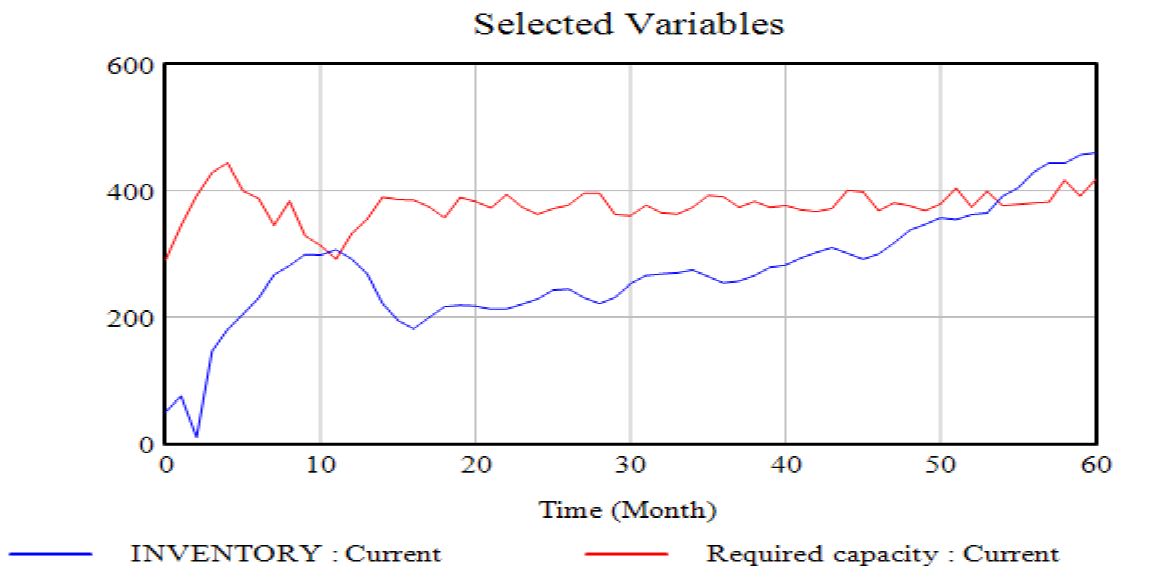


Figure 31: Comparing trends of INEVENTORY and required capacity

Figure 32 compares trends of INVENTORY and required capacity when Wi=0.35 and Wp=0.4

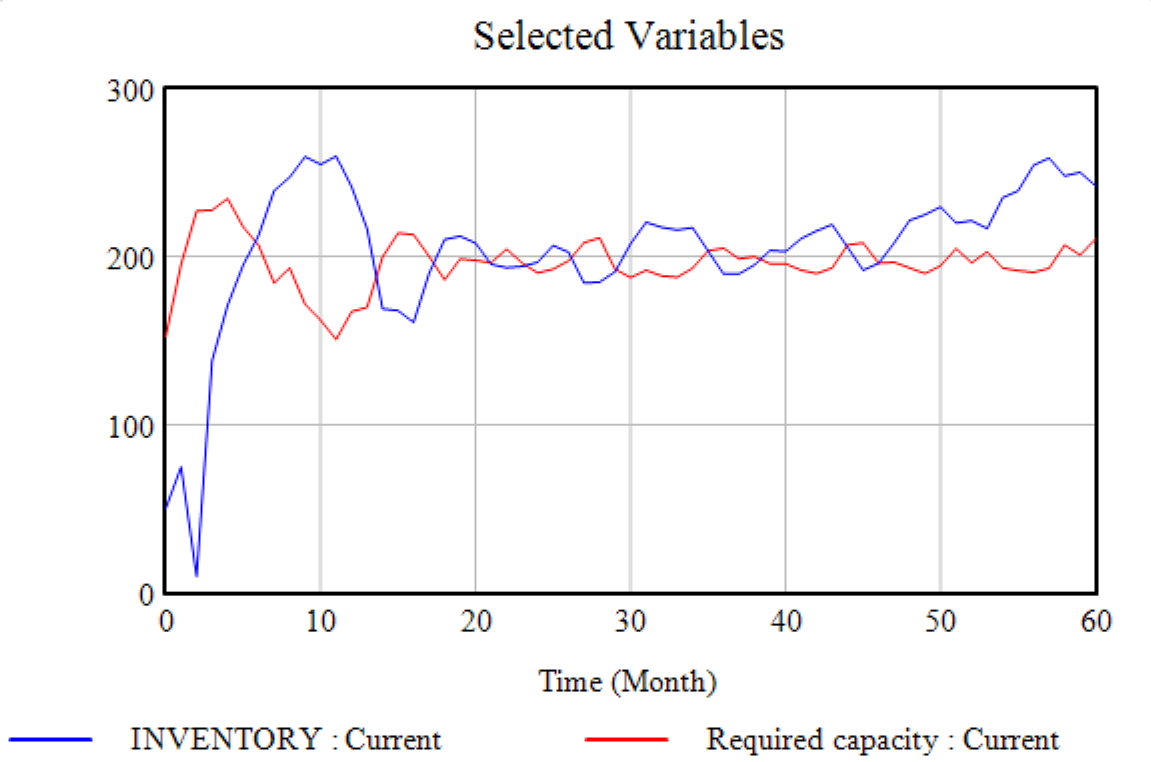


Figure 32: Comparing trends of INEVENTORY and required capacity

Table 9 summarizes the inventory values under capacity scaling study for period 10, 20, 30, 40, 50, and 60 by cases 1 through 5. Also, Table 10 summarizes the capacity required under capacity scaling study for period 10, 20, 30, 40, 50, and 60 by cases 1 through 5. Table 11 compares inventory and capacity under capacity scaling study for period 10, 20, 30, 40, 50, and 60 by cases 1 through 5.

Table 9: Inventory Level under capacity scaling study

Cases	Period 10	Period 20	Period 30	Period 40	Period 50	Period 60
wi=0, wp=0	254	208	207	203	229	250
Wi=0, wp=0.5	255	208	207	203	229	250
wi=1, wp=0	255	208	207	203	229	250
wi=0, wp=1	298	217	252	282	357	456
wi=0.35, wp=0.47	255	208	207	203	229	250

Table 10: Capacity required under capacity scaling study

	Period 10	Period 20	Period 30	Period 40	Period 50	Period 60
wi=0, wp=0	111	129	120	124	123	139
wi=0, wp=0.5	213	254	239	250	251	265
wi=1, wp=0	22	40	40.6	40.5	35,4	27.7
wi=0, wp=1	313	383	360	376	379	391
wi=0.35, wp=0.47	162	198	187	196	195	201

Table 11: Comparison of Inventory Level and Capacity required under capacity scaling study

	Period 10	Period 20	Period 30	Period 40	Period 50	Period 60
wi=0, wp=0	2.3	1.6	1.73	1.64	1.86	1.8
wi=0, wp=0.5	1.2	0.82	0.87	0.81	0.91	0.94
wi=1, wp=0	11.6	5.2	5.1	5.01	6.47	9.03
wi=0, wp=1	0.95	0.57	0.70	0.75	0.94	1.17
wi=0.35, wp=0.47	1.6	1.05	1.11	1.04	1.17	1.24

Figure 33 compare Inventory levels and required capacities under Wi and Wp conditions by periods. These results indicate that the best case occur when wi=0.35, and wp=0.47.

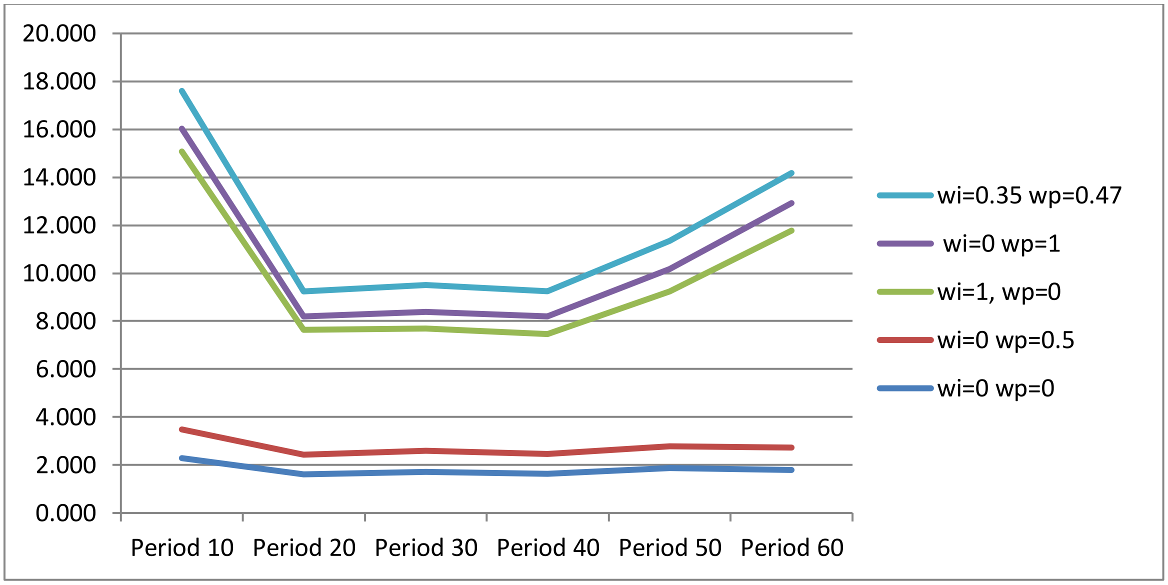


Figure 33: Comparison of Inventory levels and required capacities under Wi and Wp conditions by periods

Choosing best scenario using experts' opinions

To determine the best scenarios/case for capacity scaling we have asked our experts team to provide their assessments taking four criterions into consideration as given in the following table. The criterions/attributes are average capacity required, average inventory level, average jobs, and average ecosystem impacts. The response obtained from one of our Expert is given by Table 12.

Table 12: decision matrix for cases assessment

Case under investigation	Avg. INV	Avg. Capacity	Avg. Jobs	Avg. Ecosystem
wi=0, wp=0	H	ML	M	ML
Wi=0, wp=0.5	H	MH	M	ML
wi=1, wp=0	H	L	L	M
wi=0, wp=1	L	VH	H	H
wi=0.35, wp=0.47	H	M	M	MH

Table 13 shows the results of TOPSIS calculation using ten experts' opinions on the data gathered by Vensim simulation for five cases. TOPSIS shows that case 5 where wi=0.36 and wp=0.47 is the best case among all cases.

Table 13: TOPSIS calculation process for best case identification

Vij = Wj*Rij						
	Neg	Pos	Pos	Neg		
	C1	C2	C3	C4		
A1	0.099	0.019	0.030	0.019		
A2	0.075	0.029	0.030	0.019		
A3	0.050	0.026	0.017	0.030		
A4	0.017	0.087	0.075	0.025		
A5	0.075	0.061	0.030	0.019		
V*	0.099	0.087	0.075	0.019		
V-	0.017	0.019	0.017	0.030		
	Neg	Pos	Pos	Neg		Si*
Table of (Vij-V*)^2		Distance to Ideal			SUM	SQRT
A1	0	0.004533456	0.001943552	0	0.006477008	0.08048
A2	0.000617439	0.003330702	0.001943552	0	0.005891693	0.076757
A3	0.002469757	0.003614043	0.003330702	0.000125929	0.009540431	0.097675
A4	0.006816246	0	0	3.14823E-05	0.006847728	0.082751
A5	0.000617439	0.000657916	0.001943552	0	0.003218908	0.056735
Table of (Vij-V*)^2		Distance to anti Ideal			SUM	SQRT
A1	0.006816246	0	0.000185682	0.000125929	0.007127857	0.084427
A2	0.003330702	9.25195E-05	0.000185682	0.000125929	0.003734832	0.061113
A3	0.001080037	5.20422E-05	0	0	0.001132079	0.033646
A4	0	0.004533456	0.003330702	3.14823E-05	0.00789564	0.088857
A5	0.003330702	0.001737311	0.000185682	0.000125929	0.005379624	0.073346
	Si*	Si-	Sum	C*i		Ranking
A1	0.080479859	0.084426635	0.164906494	0.51		3
A2	0.076757366	0.061113275	0.137870642	0.44		4
A3	0.097675131	0.03364638	0.131321511	0.26		5
A4	0.082751001	0.088857414	0.171608415	0.52		2
A5	0.056735418	0.073345917	0.130081335	0.56		1

10. Implications

The main contributions of this article are discussed below in subsections named method contribution, theoretical contribution, computer software contribution, managerial contribution, and policy contribution.

10.1 Method contribution

The proposed method identifies key resilient factors and sustainability indicators important to the production system and manufacturing. By the helps of experts in the field, author obtained responses to a questionnaire for determining the impacts of resilient factors on sustainability indicators for the purpose of determining dynamical impacts of such factors on the mentioned indicators. Using Fuzzy DEMATEL approach author was able to determine this dynamical structure which is employed as a dynamic hypothesis (DH) of the problem. This approach helps in developing DH using scientific decision-making approaches. To the best of this author knowledge, this approach is new and not being seen in the literature yet.

10.2. Theoretical contributions

Putting all together, author contributed several theoretical concerns in production area as described below. First, giving new look to the production system by improving production process through resilient factors and sustainability consideration. Understanding of systems' level of sustainability and resiliency gives engineers, investors, managers, policy makers, researchers and academics a precise view for the extension of the problems they are dealing with, and how they should to deal with. Second, this paper is among the rare studies that integrate fuzzy DEMATEL and system dynamics approach to present the future of system in a form of trends as modeling of the problem allows. Third, we know that system dynamics is based upon the global and holistic vision hence it is used for solving specific problems and analyzing complex systems. This article has shown that this approach is suitable for studying dynamic indicators' performance. Fourth, previous studies have neglected several benefits of dynamics performance trending of sustainability and resiliency integration of good production system as they are being investigated in this study. System dynamics is an appropriate and suitable approach for researchers, practitioners and scholars to examine the interrelationships exits among applicable variables. Fifth, a new technology in a form of a new system dynamics computer model ready for simulation is provided that is able to help investors and policy makers in their ways of making precise decisions. Lastly, author inquired experts' opinions from industry in gathering data which is in need of keeping proper manner for dealing with the ambiguity of input data.

10.3 Computer software contribution

Good production industry within the context of systems' sustainability and resiliency is an essential undertaking in a sense that it ponders the environment and economic of the society and hence the life of people. The use of a newly developed software or computer simulation program for good producing industry is a must providing that it can measure all necessary indicators that are important to all beneficiaries. Investors always have eyes on the growth of investments made but the community certainly look into the economic growth of city and the purity of land, air, and water of their region. Here, the computer simulation program under study is a new technology and its usage in most good production industries is at the verge of origination. This paper aims at analyzing the interrelationships among the resiliency factors and its impacts on sustainability of good production indicators taking social, economic and environmental dimensions of the problem into consideration. Hence, this study's outcome and solution procedure can thoroughly act as a guideline for managers and decision makers in good production and manufacturing systems as well as other industries.

10.4 Managerial Insights

To determine the behavior of economic indicators (total cost, net sales, investments), social indicators (job creation, wages and salaries, health and safety of workers), environmental indicators (destruction of natural resources, and impacts on ecosystem) under the resilience main factors of capacity management, demand management, multi sourcing, risk management, and contracts this model can be used as a handy tool.

This study encompasses managerial insights listed below:

1. Knowing the impacts of risk on sale, policy maker can use this computer simulation to study risk right before taking any actions for implementation.
2. Studying on the trend of job creation is possible using this computer simulation program.
3. Since employees' wage, safety, and health are the key benefits that they get, the proposed computer program generates results that can be used by managers.
4. By using proposed computer simulation program, policy makers can simultaneously study the trends on: sales, job creation, wages and salaries, destruction of natural resources and impacts on ecosystem taking one or more resilience factors into consideration.

11. Conclusion

This study is about a production system taking basic production process as well as production resiliency factors and sustainability indicators important to such systems into consideration. The dynamic hypothesis of the problem was determined using resiliency strategies and sustainability factors along with the DEMATEL approach in fuzzy environment, to determine the dynamical structure of the problem. In this study, manufacturing system was characterized by capacity scalability taking system dynamics approach to better reflect the dynamic nature of capacity scalability process. This paper contributes to the knowledge of capacity scalability and its integration with the resiliency factors and the overall impacts on the sustainability indicators of goods production. In addition to that, this model considers the amount of sale, investment, new capacity development, job creation, and customer satisfaction by duration. Each of these refinements was defined and introduced into the dynamic model of problem in the form of new modules with traceable trends. Various measures important to management are implemented into the model of problem. These measures are: Work in process, production level, reject rate, rework level, rework rate, inventory level, delivery rate, desired delivery rate, customer demands, backlogging, customer satisfaction, investment, new capacity generation, job creation, income generation and ecosystem impacts. Capacity scaling policies are used with trends reported for each case in the body of article.

The study of goods industry in a region is of high concern to developers for measuring how well they are doing their duties and how well people are seeing their region growing with respect to their standard of livings and values. Investors and regional policy makers have to take many issues into consideration to be able to respond to variety of questions arise right before, during and after the development. To have suitable response for questions arise, a simulation program is a must to use as an aide for designing questions and then executing the program to get appropriate response. Analyst employed different approaches to find the trends that goal variables are showing by the passage of time. SD is known as a good tool for this purpose as it is used in many different types of problem solving. Vensim simulation software was used to simulate the model of the problem. To make sure results are solid, sensitivity analyzed was performed on capacity scaling watching the behaviors of capacity scaling taking acceptable values for Wi and Wp into consideration. Such behaviors are shown in the body of article. Due to the fact that limited studies appeared in the literature on the impacts of production resiliency factors on sustainability indicators using system dynamics approach this research can play a big role in originating other studies in this area. The model presented here uses key resiliency factors which can be extended to include other factors important to the goods production managers and engineers. New factors such as suppliers' timely response, transportation availability, raw materials availability, foreign market availability and so on may be added to a new model. Future research directions that are extracted from this study are: (1) more resilient strategies can be identified for dynamic hypothesis modeling using combined DEMATEL and ANP; (2) an array of sustainability factors can be used to measure deeper and vaster performances of sustainability dimensions; and (3) new sophisticated scaling policy are also possible to propose.

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