Using Systems Dynamics in Modeling of Dynamic Capabilities: A Review Study

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Abstract—Dynamic capabilities play a vital role in organizations' long term success because they enable top management to profitably invest the available resources in respect to the market dynamism. In addition, it has been proved that system dynamics is a useful approach for explaining the complex system and predicting the future progress. The main aim of this study is to examine and discuss the theoretical and empirical application of system dynamics that involving dynamic capabilities through a systemic analysis of the literature in order to highlight the key research themes and development trends of the key contributions to data as well as to provide an overview of system dynamics applications to dynamic capabilities literature for future research to build on. The study is also covering the surrounding knowledge and the required steps to build system dynamics model of dynamic capabilities.

Keywords— *system dynamics, dynamic capabilities, analytical analysis.*

I. INTRODUCTION

A company's ability to retain profitability over the long term depends on the strength of its dynamic skills in many ways, including the capacity to create and modify business models [31]. Growing interest in the perspective of dynamic capabilities has led to numerous studies using a variety of techniques, analyses, and methodologies, but not to an increase in simulations and models like the system dynamics model [25].

It is challenging to research how dynamic skills might be employed in practical managerial decision making due to the lack of a quantitative model and insufficient knowledge of dynamic capabilities [22]. The most effective technique for a management scientist to use a computer today is to imitate the system being studied through computer experiments. A computer is utilized in these simulations because of its capability and speed in simulating the behavior of the system under study throughout time. This creates a framework platform for conducting research studies that evaluate organizational strategies before being put into practice [21]. A business model explains the framework for how a company develops and provides value to clients as well as the methods used to take a cut of that value. It is a coordinated group of components that includes the movements of expenses, revenues, and profits [31]. In order for the model to be able to predict the direction of significant changes in system performance, the model's mechanisms must accurately reflect the mechanisms of the actual system. Performance in this context refers to the generation of patterns and dynamic tendencies, such as stable or unstable, oscillating, exponentially expanding, self-correcting, or in equilibrium, rather than the prediction of the future system state and the precise numerical values of variables [21].

This research is targeting to focus on using system dynamic in modeling dynamic capabilities.

- Identifying dynamic capabilities, and offering information about their importance and their most famous types.
- Giving overview about the system thinking that includes the science of system dynamics.
- Explaining system dynamics, its underlying structures and its related techniques that should be followed in order to design system dynamic model of dynamic capabilities.
- Reviewing and classifying previous literature; all surveyed papers are compared and analyzed from several perspectives.

The rest of the paper is structured as following; section two defining dynamic capabilities, followed by section three which gives overview about system thinking that includes system dynamics, then section four where system dynamics is identified as well as Project dynamics' underlying structures and the major diagrams of system dynamics; causal loop diagram (CLD) and stock and flow diagram (SFD) followed by a definition to the business model and an overview of system dynamics strengths and weaknesses, The classification of literature that linked system dynamics with dynamic capabilities are presented in section five, followed by analysis and discussion in section six and finally the conclusion at section seven.

II. RELATED WORK

A. Dynamic Capabilities

When time-to-market and timing are crucial, the pace of technological change is rapid, and it is challenging to predict the nature of upcoming competition and markets, the term "dynamic" refers to the capacity to renew competencies in order to achieve congruence with the changing business environment. The word "capabilities" highlights the crucial function of strategic management in effectively integrating, reconfiguring, and adapting internal and external organizational skills, intellectual dialogue, some acceptable definitions resources, and functional competences to meet the demands of a changing environment [32]. Reference [11] defined the expression of dynamic capabilities as: "The firm's processes that use resources—specifically the processes to integrate, reconfigure, gain and release resources—to match and even create market change. Dynamic capabilities thus are the organizational and strategic routines by which firms achieve new resource configurations as markets emerge, collide, split, evolve, and die."

B. System Thinking

According to reference [40] over the past 60 years, system thinking has changed and grown, and it is now influencing science more and more. In order to grasp the patterns and relationships of complex situations, system thinking is a science that works with the organization of logic and integration of disciplines. Principles of organization or the theory of self-organization are other names for system thinking, and "systemic" or "holistic thinking" is required when applying it. It is a science centered on comprehending relationships and connections between objects that appear to be unrelated. System Dynamics and System Analysis are two more ideas incorporated into System Thinking.

C. System Dynamics

When faced with complex dynamic systems, system dynamics' principal objective is to enable people to make wiser judgments. The methodology offers tools and methods for modeling and analyzing dynamic systems. To assist everyone comprehend the behavior of the system, key findings from models can be communicated. It involves simulation modeling that supports systems thinking methodologies and is based on feedback systems theory. It can be used to address dynamic issues that develop in intricate social, managerial, economic, or ecological systems. It is applicable to biological, managerial, economic, ecological, and social systems [28].

The system dynamics model offers businesses possible strategies based on the target indicators, offers an unbiased evaluation of the target indicators' sensitivity to changes at one or more parameters, establishes and corrects their controllable limits, pinpoints specific causes of variation, and, as a result, ensures that the necessary management changes are made. Mathematical softwares are now used for enabling system dynamics modeling. Some examples are Vensim , AnyLogic, iThink , Maple, Maxima, and MathCAD (computer experiments software) [2]. These simulation models' value could potentially help to explain highly important phenomena like the recent global financial crisis [21].

a) Project dynamics' underlying structures

According to reference [39] based on the key idea that incorporated into project models, the structures system dynamicists have used to model projects can be divided into four types. The categorization links project model structures to the system dynamics methodology and offers a meta-structure of those structures. The four groups of model structures are:

1. Features of the project: System dynamics focuses on modeling characteristics present in real systems. These in projects include decision-making, managerial mental models, and development procedures. The ability to replicate realistic project dynamics and closely link to the experiences of working managers is increased by modeling key elements of actual projects.
2. Rework cycle: The dynamics of particular model types are mostly driven by a collection of canonical structures in system dynamics. The rework cycle is the standard organizational structure for system dynamics project models.
3. Project Control: The goal of applying system dynamics in numerous disciplines is to model, analyze, and improve the control of dynamic systems. Modeling the controlling feedback loops through which management tries to close gaps between project performance and targets directly applies one foundation of system dynamics to project management because project managers aim to deliver on time, on budget, and with the quality and specifications required.
4. Ripple and knock-on effects: System dynamics uses policy resistance and unintended effects as its primary justifications for many undesirable behaviors. The phrase "ripple effects" is often used in projects to refer to the main negative outcomes of well-intentioned project control initiatives. The concept of policy resistance is captured and used in initiatives that model ripple effects. "Knock-on effects" refers to the secondary consequences of project control efforts, or the ripple effects, which are frequently brought on by processes that result in an

excessive amount of or harmful concurrence, or by human factors that magnify the adverse effects through mechanisms like morale. The idea of unforeseen side effects is used to describe project behavior and performance in knock-on effect modeling.

b) Causal Loop Diagram (CLD)

The core tenet of the system dynamics model is that any complicated social organization has inherent causal structures that give birth to continuous dynamic orientations. Hence, there must be a match between the parameters and framework that could be altered in the system and the parameters and framework of the actual system for a model to accurately predict the effects of real system changes [21].

The two-way causality or feedback is the main concept that system dynamics uses to comprehend system framework. It is supposed that making the individual or social decisions are based on the knowledge of the status of system or the surround environments. The decisions result in actions that are meant to prevent unwanted outcomes from occurring or keep the system in its desired state. More decisions and modifications are then brought about by new knowledge regarding the system condition. Each such closed chain of causal links creates a feedback loop in the continuous process. Models of system dynamics, which are essentially representations of closed-system with the majority of the variables occurring in feedback interactions and being endogenous, are composed of numerous such loops linked together. [21].

Figure 1 shows a simple example to CLD, it illustrates that increase or decrease in the birth rate affect correspondingly in the population rate. Also, the increase in the population rate increases the rate of the death rate while the increase in the death rate causes in decreasing in the population rate. It can be seen in the figure that there this positive feedback reinforcement loop clarifying that the increase in the birth rate affect positively in the population rate which plays its role in enforcing the birth rate increase, there is also negative reinforcement loop which indicate that population increase enforces increasing death rate while increasing death rate enforces decreasing population rate.

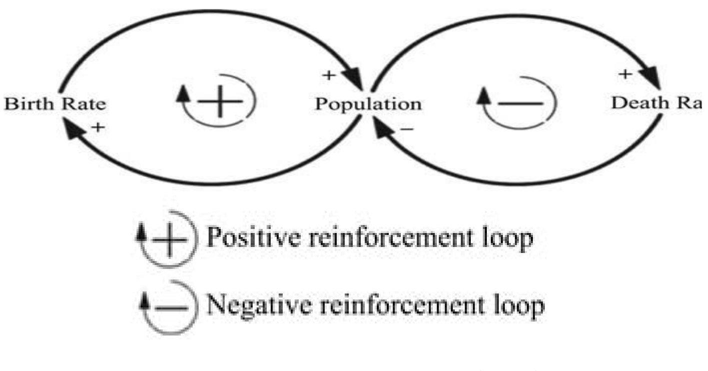

Figure 1: Causal loop diagram representation, adopted from reference [37]

c) Stock and Flow Diagram (SFD)

Stocks and flows are the structure blocks of any system dynamics models [9]. In order to determine whether a specific factor is a stock or not, the following question can be asked: "Does it accumulate?" [5]. According to [38] Stocks are an amount of a particular thing. A nice illustration of a stock is water in a tank. Reservoirs are another name for stocks. The units of all the stocks that are linked to flows will be the same, i.e., a quantity of water, a quantity of carbon, or a number of people, flows link sources and sinks or stocks. Any stock that the flow enters or exits will be increased or decreased, respectively. All of the flows that are linked to a stock will have units equal to the stocks' units per unit of time. For instance, this could be tons of carbon dioxide per year or liters of water per hour. We display information as a "converter/constant" when it is necessary for the model to use it as a constant or when a computation is required. It can be seen in figure 2 how the CLD in figure 1 can be transferred to SFD, where the population is representing the stock, and birth is representing the inflow while the death representing the outflow. According to reference [38] the following steps are required to start the SFD: 1; determine what kind of energy or material is being transferred, 2; describe the stocks and the flows that is, how matter or energy travels between the stocks, 3; define the system's perimeter by indicating what stocks and flows you are quantifying and what is outside. There must be sources or sinks to indicate any flows into or out of your target system, respectively, 4; using the aforementioned iconography, draw a diagram that depicts the main reservoir stocks, flows, sources, and sinks, 5; could there be any variables (like temperature) or derived quantities (like flow per person) that are influencing a flow? If yes, designate a constant or converter to symbolize this relationship. 6; make linkages from stocks to flow-regulators, from one flow to another flow, and from convertors to flows, 7; verify the diagram to ensure that all flows indicate the movement of whatever is in the stocks per unit of time, 8; look for regulatory elements in the flow diagram, such as stock-limited flow, feedback acceleration, and feedback inhibition (negative feedback), 9; look for connections in the diagram between the flow of various materials or energies (such as the usage of natural resources in relation to the pace of population expansion).

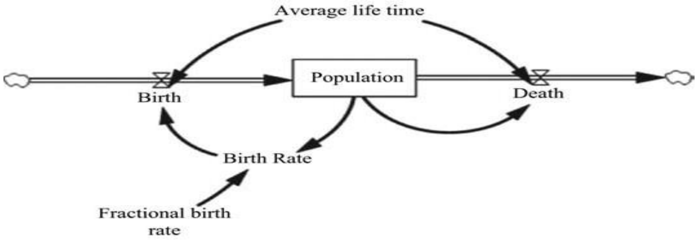

Figure 2: Stock-flow representation, adopted from reference [37]

d) Business model Definition

A business model is a blueprint for the "architecture" of the organization and finances of a company. This model makes assumptions about how revenues and costs will behave as well as about the probable behavior of customers and competitors. If a profit can be made, it describes the parameters of the strategy needed to do so [29].

The business model plays a crucial role in identifying unmet consumer demands, designing the organization and technology that will meet them, and, last but not least, collecting value from the operations. The paradigm won't last very long, at least not by for-profit businesses, if creation, delivery, and capture are not balanced properly. The business model explains, in essence, the (industrial) logic by which clients are handled and money is made [31].

How a company model's components differentiate it from rivals in the market is utmost importance. Although competitors may attempt to copy a variety of business models, including Power-by-the-Hour, in theory this may take several years to really happen. Competitors might gauge their chances differently and might not have the organizational flexibility to swap business models. In other words, their dynamic capacities may be less strong. In the interim, the pioneer may gain benefits, such as perfecting the abilities necessary to monitor and operate aircraft engines for optimal uptime, as in the case of Rolls-Royce [31].

Today, complicated phenomena are studied through the construction and simulation of computer models. Yet, a model cannot replace an actual system or problem situation. Models must therefore simplify and abstract the reality of the problem scenario to some extent [21].

There is interdependency between business models, dynamic capabilities, and strategy. A company's dynamic capabilities' potency influences how well it designs business models. A business model affects the firm's dynamic capacities and sets limits on the viability of specific strategies through its impact on organization design. [31].

The several business dynamics models enable the detection of similarity in extremely dissimilar systems that are predicted to exhibit comparable behavioral tendencies. When customer behavior is depicted using different parameters, for instance, stock and flow will show the same exponential growth trend in a system that depicts the accumulation of clients. Time delays may play a significant role in how dynamically a system behaves. System dynamics highlights the effects of various lags in real systems, and modelers carefully look for such lags [21].

According to [28], models are clear representations of the world that let us examine relations, suppositions, and logic. As a result, they give us a much superior way to comprehend the world than our mental models do. Models are also fantastic visualization tools, while [30] defined business model as “A business model articulates the logic and provides data and other evidence that demonstrates how a business creates and delivers value to customers. It also outlines the architecture of revenues, costs, and profits associated with the business enterprise delivering that value.”

Among the analytical techniques used in management science, computer simulation methods may be the most popular. The fundamental idea behind computer simulation modeling is that the analyst first creates a model of the target system using an appropriate software package, and then uses computer simulation to generate the system's behavior under various policy scenarios in order to choose the best possible scenario [21].

According to [34] eleven steps should be followed in order to build a coherent model; these steps will be followed as followed:

1. Defining the model's purpose: assigning the aim of building the model is extremely important.

2. Defining the system that will be modeling: before starting of modeling the required system, what is inside and what is outside the system should be clearly determined.

3. Identifying the key variables: system variables should be identified and named carefully, samewhile names should be clear and representing the reality.

4. Describing the key variables' behavior: Since the exact behavior of the variables may be unknown, so at least the main constraint should be defined in order to enable the model to be evaluated and improved later.

5. Identifying stocks and flows in the system: defining the levels of the systems and the flows that affect them.

6. Mapping stocks and flows in the diagram pad of the used software: starting in building the system in the assigned simulation software.

7. Defining flows of the system: modeling the relationships of the system.

8. Including quantitative information: entering the equations of the model elements.

9. Running the model: at the running step, the model should be act as reality, if not so, the problem should be defined and returning to the step where the problem is and correcting that problem.

10. Evaluating the model: the behavior of the model should be reasonable, if not so, it should be returned to the relationships of the model to check if there is a mistake in any of them.

11. Improving the model: searching for the reasons of any irregular behavior, once knowing them, model should be modified to act appropriately, and then a few several scenarios should be tried to test the model under several conditions. Additional structures may be also added to the model

Instead of evaluating effective models on their capacity to reliably represent reality, it is preferable to focus on how useful and appropriate they are for solving the problem situation under study. Since it is neither practical nor possible to examine all the variables or all of their potential interactions in the problem situation, the analyst should try to focus on the most crucial components and represent them in a way that is both easy to use and understand and captures the essence of the situation. In this approach, a model's value comes from its ability to more effectively advance our understanding of characteristics of masked behavior than could be accomplished by directly watching the actual system. In this way, a model can provide information at a lesser cost than the actual system while also providing knowledge more quickly and for conditions that are difficult to observe in the real world [21].

e) System Dynamics' strengths and weaknesses

The main strength of system dynamics is in assisting us in gaining high-level strategic insights on dynamical issues. We can use it to identify counterintuitive dynamics, rigorously simulate the effects of a theory or intervention, or assist stakeholders in doing so. Additionally, it encourages us to consider dynamics rather than isolated occurrences or static models. Many systems dynamics software packages enable you to view how dynamics emerge from interacting feedback loops as they vary in strength and importance as a model develops, in addition to producing outputs illustrating how variables change dynamically. This dissection of dynamics into its constituent pieces can help stakeholders and modelers alike comprehend dynamics more intuitively. For many people, thinking dynamically is a totally different way of thinking that can be challenging to adopt; System Dynamics will assist you in doing so. As a simulation technique, it is also ideal for assisting us in debating hypotheses and to investigating the 'what if?' scenarios and the potential effects of initiatives. Despite being a quantitative approach, it cannot be used to analyze systems in detail or to answer operational or more regional, or "micro," concerns. It typically depicts systems as a whole and concentrates on dynamical subsystems. Compared to the other methods in this book, it takes a lot of time to conduct. This can be a significant obstacle to its application in participatory and applied situations. Additionally, as we frequently lack the assistance of prior modeling and quantification of these concepts to guide our adoption of them, it can be challenging to include social and "soft" variables in a model [41].

III. MODELING OF DYNAMIC CAPABILITIES USING SYSTEM DYNAMICS

The fundamental factors that hold an organizational system's structure together in connection to its surroundings are revealed through simulation. Such information will help prevent basic planning mistakes and enable suitable proactive, well-targeted response [21].

By assisting managers in extending, modifying, and reconfiguring current operational capabilities into new ones that better suit the environment, dynamic capabilities have been offered as a way to deal with tumultuous settings. However, because dynamic skills have been perceived as an elusive "black box," managers will find it challenging to make wise choices in challenging situations if they are unable to accurately measure dynamic capabilities [22].

The database of the reviewed studies has been arranged by year of publication to involve the period from 2002 to 2022. For each item, the following elements have been highlighted; the year of publication, author (s), sector/category that is focused on by the application, type of study (theoretical/ applied), simulation software if used, purpose/ target of developing the model, and type of contribution of dynamic capabilities as sometimes the studies is mainly depends on dynamics capabilities and other times the models include dynamic capabilities as a secondary parameters.

A summary of reviewed studies classification is listed in table 1.

TABLE 1: Summary of Reviewed Studies Classification

Year	Author(s)	Sector/ Category	Theoretical/ Applied	Simulation software	Purpose/ Target	Contribution; Mainly/ Partial
2002	[27] Stamboulis et al.	Innovation management	Applied	Indiscernible	Describing the creation and application of a framework for analyzing the complex dynamics of production and developing both of product and process, and production development in the context of a resource-based view of firm activities.	Partial
2004	[17] Hazy	Organizational Transformation	Applied	VenSim	Making Organizational Transformation Between Leadership Initiatives and development of dynamic capabilities.	Mainly
2006	[6] Chirico	Family Firms	Applied	VenSim	Outlining the beneficial dynamic links between knowledge, capabilities, dynamic capabilities, entrepreneurial success, and trans-generational value in family businesses using computer simulations in system dynamics.	Mainly
2007	[7] Chirico	Family Firms	Applied	VenSim	Demonstrating the beneficial dynamic links between knowledge, capabilities, dynamic capabilities, entrepreneurial success, and transgenerational value in family businesses using computer models of system dynamics.	Mainly
2008	[19] Kortelainen et al.	Industrial firm	Applied	VenSim	Gaining profit form learning in innovation	Mainly
2009	[13] Garzia et al.	Strategic Management	Theoretical	Not used	Concentrating on the relationship between resource dynamics and the development of new tactics.	Partial
2009	[33] Weitert et al.	Organizational Management	Applied	Indiscernible	Investigating the microfoundations of the dynamic capabilities in respect to radical innovation.	Mainly
2010	[26] Romme et al.	Management	Applied	Ithink	Enhancing the development of dynamic capabilities.	Mainly
2011	[8] Chirico et al.	Family Firms	Applied	VenSim	Analyzing the effects of paternalism on dynamic capabilities and, as a result, value creation in family firms.	Mainly
2011	[18] Kortelainen et al.	Mobile handset vendor business	Applied	Indiscernible	Overcoming obstacles in an empirical case study on the business of mobile phone vendors' competitiveness.	Partial
2013	[14] Gilkinson et al.	Construction	Applied	VenSim	Comprehending the historical development and current state of the construction industry, as well as the dynamic capabilities required for a business to achieve a more sustainable and competitive future.	Mainly
2013	[15] Garzia	Strategic Management	Theoretical	Not used	Utilizing a system dynamic based process model for studying strategic innovation.	Partial
2014	[4] Bezerra et al.	State revenue	Applied	Indiscernible	Assessing and managing capabilities of customers' information technology that must gradually be applied to outsourcing partnership.	Mainly
2015	[1] Baker et al.	Strategic management	Theoretical	Not used	Modeling the processes involved in developing and changing strategies, including those that take place at various organizational levels.	Partial
2015	[23] Rahmandad	Organizational Management	Applied	Indiscernible	Describing the challenges that endogenous growth possibilities and competition place on managers to concentrate in the short term.	Mainly
2018	[25] Rengkung	New product development	Theoretical	Not used	Creating a model of dynamic capacities based on the system dynamics methodology and the business environment.	Mainly
2019	[24] Rebs et al.	Sustainable supply chain management	Applied	VenSim	Proposing a system dynamic model for including the pressure influence from external stakeholders, such as the government, and shareholders.	Mainly
2021	[12] Forliano et al.	Organizational Management	Applied	Stella Architect	Reconstructing the complex causal connections between environmental dynamism, capabilities development, and firm performance.	Mainly
2021	[16] Huiping et al.	Digital Context	Applied	VenSim	Investigating the various ways that global knowledge searching affects the dual innovation of enterprises in the context of digital transformation.	Partial
2021	[36] Yuana et al.	Digital companies	Applied	VenSim	Defining business model innovation using partnership scenarios and system dynamics.	Partial
2022	[20] Lin et al.	Aircraft leasing industry	Applied	VenSim	Recognizing the sustainable growth of the Chinese aircraft leasing industry.	Mainly
2022	[3] Bayu et al.	sustainability management	Applied	VenSim	Proposing a system dynamic model for sustainability management from the perspective dynamic capabilities.	Mainly

IV. ANALYSIS AND DISCUSSION

By analyzing the various literatures, it has been found that modeling of dynamics capabilities have been mostly used in the sector of management as 45% of the results related to management, 14% related to industry, 14% family firms, 9% digital firms and 18% is the percentage usage in other fields as seen if figure 3, while figure 4 illustrates that models which applied the conceptual models using simulation software represent the percentage of 67% of the total models in compare to 33% which represents the percentage of the theoretical models without applications. Regarding the popularity of simulation software, as it can seen in figure 5 that the most famous simulation software in modeling dynamic capabilities is VenSim as 85% of the mentioned simulation softwares is VenSim while both of IThink and Stella software take percentage of 8%. Concerning the contribution types of dynamics capabilities, it has been illustrated in figure 6 that 68% of models depend mainly on dynamic capabilities while 32% use dynamic capabilities as a secondary parameter. Concerning the interest in the subject of using system dynamic in modeling dynamic capabilities; figure 7 shows the number of articles in chronological order, the graph demonstrates a notable rise in interest in the subject in 2021.

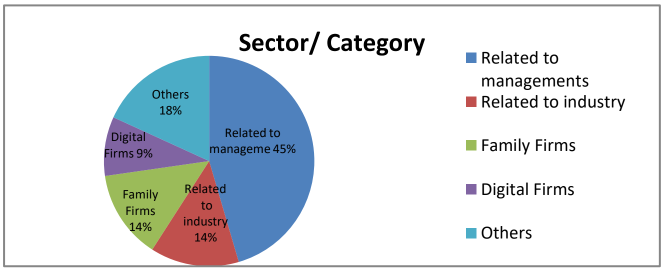

Figure 3: Distribution of Sectors/ Categories

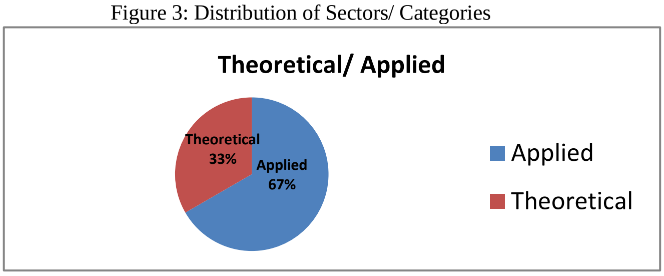

Figure 4: Distribution of theoretical and applied models

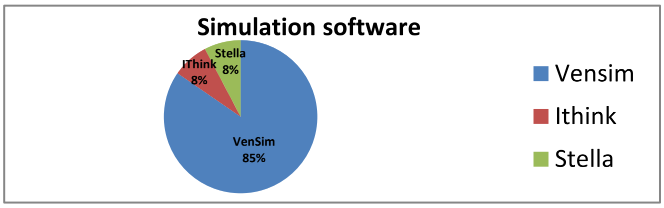

Figure 5: Distribution **of simulation software**

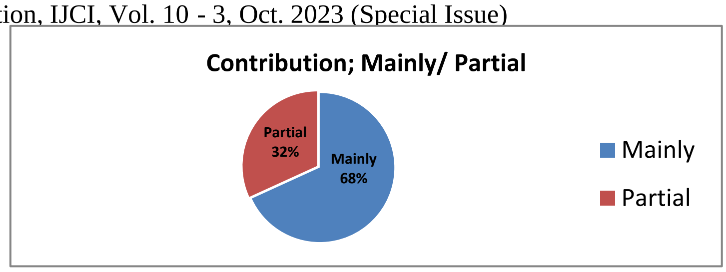

Figure 6: Distribution of contribution types

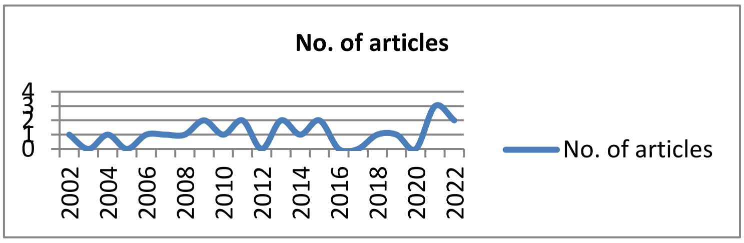

Figure 7: Number of articles in chronological order

VI. CONCLUSION

Modeling system dynamics of dynamic capacities plays an important role in evaluating the business performance as well as predicting the future success by supposing various scenarios. In this study it has been focused on studies that linked system dynamic with dynamic capabilities, it gave a construct explanation to developing system dynamic model and description to the dynamic capabilities. It has also classified the surveyed literatures based on several perspectives and conducted comparisons and analysis to them accordingly.

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