A Research on Systems Thinking

Based on Three Dimensions Thought

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【Abstract】
Nowadays, the performance measurement system has been well developed. And the relationships between these performance measures are playing important roles in management science. However, the effective method to analyze these relations is still underdeveloped and attracts more and more concerns. After reviewing relevant research, by adopting and further extending the essential theories of Systems Thinking, we propose a three-dimensional Systems Thinking to achieve better analysis, control and decision-making. In this paper, the rationality of the three-dimensional thought is proved first, and the modeling method is then provided in theory. Finally, a manufacturing enterprise is illustrated as an example for practical implementation.

【Key words】
Systems Thinking, three dimensions, performance measure, causal relation

1. Introduction

Due to the inconstancy of market circumstances and the diversity of customer requirements, and in order to catch up with the dynamic business world, enterprises are operating with more and more continuous and rapid variations[1]. More exactly, managers always use plentiful and specific real-time operating details to make appropriate analyses and decisions[1]. In this way, their operation systems will be monitored and adjusted in time, and system performances will get continuous improvement[1]. At present, managers generally supervise their enterprises and acquire reliable decision support through relevant performance measurement systems[2][3].

Many researchers have been studying performance measurement systems for a longtime and have proposed a great deal of mature models and system architectures[4]. The Return on Investment (ROI), the Balanced Scorecard (BSC) suggested by Kaplan and Norton, and the Supply Chain Operations Reference (SCOR) offered by the Supply-Chain Council are the three most famous frameworks[5]. ROI is a finance-oriented method, whose performance indicators are all related to finance affairs[5]. BSC is a strategy-oriented measurement, variables in which can be classified into four categories-the finance-related, customer-related, internal process-related, and innovation and learning-related[1]. BSC has been widely used to analyze supply chains and enterprises. Brewer and Speh have even proposed a BSC supply chain performance measurement system[6]. SCOR is process-oriented, seeking performance measures from process aspects[5]. Many people have used SCOR to establish their models, like Gunasekaran, Patel, and Tirtiroglu who have presented their SCOR performance measurement system to study supply chains[7]. Furthermore, a number of performance measurement systems proposed by others researchers (e.g. Beamon[8], Huo[9], Andersson[10], Cooke[11]), and some commonly used methods analyzing variables such as the Key Performance Indicators-method and the Benchmarking-method all contribute different cognitions and thoughts to research.

However, a mature performance measurement system is not enough for assisting management. On the one hand, when choosing performance measures, people are always considering completeness and orthogonality. That is, they want indicators that can completely describe their actual system without overlapping. However, most choices are made according to guiding principles and reference models only, and need to meet the special requirements of different enterprises. So, there are various relations existing between the chosen indicators, which Norreklit[12] has statistically mentioned in his studies. These causal links may reduce the efficiency and scientificalness of a performance measurement system. Meanwhile, some new and necessary parameters can be found recognized by analyzing relations between the former variables[3]. Therefore, seeking these causal links will facilitate a continuous improvement in performance measurement systems.

On the other hand, huge amounts of practices have shown that managers are always confused with problems like that: why the stock suddenly increased a lot last month? How to adjust the productivity to a certain level? What will be affected if the product price changes? In fact, the key indicators and parameters which managers pay attention to usually vary with time, and are always related to or act on each other. Actually, many complex phenomena resulted from the interactions between parameters[13], and it is just these relations that make a system dynamic and complicated, as mentioned in the book *The fifth discipline*[14]. Currently, when dealing with performance measurement systems, most enterprises often ignore the dynamic relations between parameters and the process of engendering organization performances[3]. As a result, they often fail to correctly solve the problems caused by interactions and cross feedbacks. Obviously, managers are starved for a method with useful tools to help them analyze their system (which is full of correlations), and offer support for their decisions.

At present, research on indicators and their causal relations are insufficient, with relative theories just at the beginning stage[3][15]. Currently, some methods, such as the Cognitive Map[15] and Strategy Map[16], are used to solve these kinds of problems. Among them, Causal Loop Diagrams and Systems Thinking (ST), coming from System Dynamics and considering the system and makes causal relation models from a holistic view, offer researchers a comprehensive and appropriate method to analyze these problems[17]. Based on the theory in the book *Business Dynamics*[17], Sherwood proposed a model that helps people monitor and adjust their systems through the connection of *levers → balancing loops → driving factors → business growth engine*, and allows further simulations on computers[18]. However, ST models rely too much on the subjective cognitions and experiences of designers. In other words, the models are so variable that different people may give models having little in common. Consequently, how to seek key indicators with causal links and to find a way to make a comprehensive model with more objectivity is the main problem this paper needs to solve.

2. The Three-Dimensional Systems Thinking

2.1 The three-dimensional model of a system

Any system can be described as the following sentence: after A acts on B, C is obtained.

A can be considered as an input vector, B as a vector which represents inner characters of the system, and C as an output vector. Assuming that $A = (a_1', a_2', \ldots, a_m')$ is m-dimensional ($m \geq 1$), $B = (b_1', b_2', \ldots, b_n')$ is n-dimensional ($n \geq 1$)， and $C = (c_1', c_2', \ldots, c_p')$ is p-dimensional ($p \geq 1$), this thought can be shown as Fig.1.

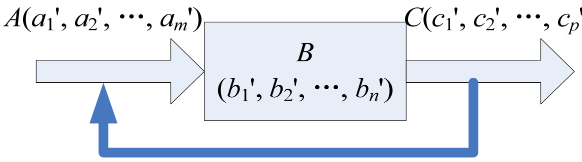

Fig.1. System description

The input can also be regarded as a set of control inputs, the system as a set of controlled objects, and the output as a set of performance outputs. Considering that the input is m-dimensional, there must exist m independent controls $a_1, a_2, \ldots, a_m$, any kind of controls can be represented by the combination of which. Choose such an $A = \{a_1, a_2, \ldots, a_m\}$ as a control set. In the similar way, an object set $B = \{b_1, b_2, \ldots, b_n\}$ and a performance set $C = \{c_1, c_2, \ldots, c_p\}$ which can be completely described without overlapping could also be constructed.

In terms of the above definitions, controls A, objects B, performances C could be respectively considered as three dimensions for researchers and managers to learn a system. That is to say, controls $(a_1, a_2, \ldots, a_m)$, objects $(b_1, b_2, \ldots, b_n)$, and performances $(c_1, c_2, \ldots, c_p)$ can separately represent the system in the aspects of controls, controlled objects, and performances. Thus, the system could be described as Fig.2, which shows that for any given i, j, an action of control-a_i on object-b_j will influence an element (represented by a cube in Fig.2) of performance-c_k ($1 \leq i \leq m$, $1 \leq j \leq n$, $k = 1, 2, \ldots, p$). For example, assuming that $i = 1$ and $j = 1$, if the cubes whose B-coordinates are b_1 are blue, coloring those whose coordinates on A-axis are a_1 with yellow, then there will be p cubes appearing green, just as Fig.2 presents. Actually, it is rare that every a_i can directly act on each b_j. In this case, if their influences on c_k's relative element are considered to be zero ($1 \leq i \leq m$, $1 \leq j \leq n$, $k = 1, 2, \ldots, p$), the model will still work. Similarly, to deal with the instance that c_k has nothing to do with a_i or b_j ($1 \leq i \leq m$, $1 \leq j \leq n$, $1 \leq k \leq p$), just define the corresponding element to be empty.

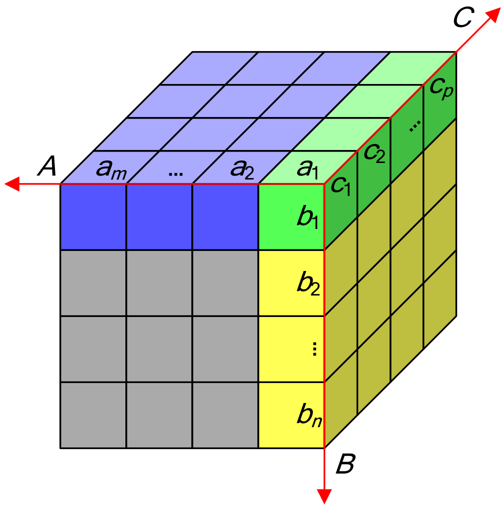

Fig.2. Three dimensions of a system

This thought can be used for setting models to any entity that works with motivations. For instance, a college student who wants to improve himself all-around may spend his time, energy and money on study, social work and entertainment. He / She would then obtain experience, knowledge and satisfaction. Thus a model as follows can describe the student.

Controls: A = {time, energy, money, ...}
Objects: B = {study, social work, entertainment, …}
Performances: C = {experience, knowledge, satisfaction, …}

Another example is about a manufacturing enterprise, which invests in staff, equipments, and operations to every division, to improve enterprise performances.

Controls: A = {human-ware, material-ware, operating-ware}
Objects: B = {procurement, production, logistics, sales}
Performances: C = {quantity, quality, time, money}

2.2 The three-dimensional model of Systems Thinking

ST has given a current business model[18] describing a motivated entity, as shown in Fig.3. The modeling method pays attention to looking for a core growth engine, which pushes the whole system to revolve. Afterward, it makes several levers act on the growth engine, by first operating on their corresponding balancing loops, then on different driving factors, to realize all-around controls to the entire system. Particularly, ST integrates control resorts into the causal model. This strategy facilitates analyzing, controlling and decision-making. Besides, it is a double-layer model, not only allowing managers to overview the whole system through the core growth engine, but also offering them more details about the lower layer (the exact loops).

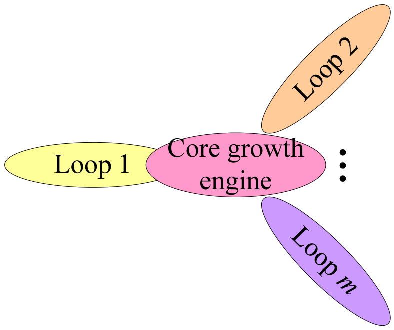

Fig.3. Current business model of Systems Thinking

In accordance with the three-dimensional model shown in Fig.2, adopting the essential thoughts of ST, any entity working purposefully could be fitted to a three-dimensional ST model. This is shown in Fig.4. The key points of establishing models are as follows.

i. Separately picked up in the three-dimensional model of system, the controlled objects have become single entities. Thereby, besides the core growth engine of the system, every controlled object also has its own growth engine. Name the growth engine of object-b_j as b_j-engine ($1 \le j \le n$).

ii. According to ST, a control acts through a corresponding balancing loop, which contains many kinds of parameters. Naming the loop corresponded with control-a_i as a_i-loop ($1 \le i \le m$), then applying control-a_i on b_j-engine ($1 \le j \le n$), a new balancing loop, an embodiment of a_i-loop, is formed, and named as a_{ij}-loop, in which parameter-c_k will become c_{ijk} ($k = 1, 2, \ldots, p$).

iii. For a certain k ($1 \le k \le p$), there exist several relations between c_{ijk} ($1 \le i \le m$, $1 \le j \le n$), totally named as c_k-connection.

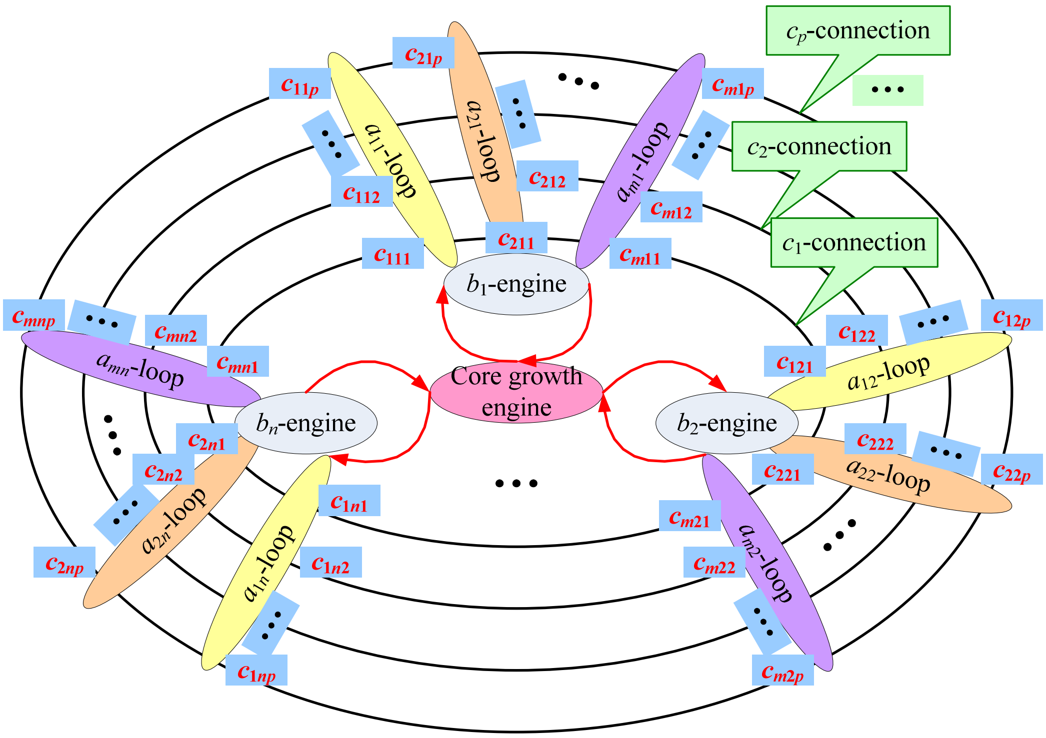

Fig.4. Connections of three dimensions and core growth engine

It is concluded in Fig.2 and Fig.4 that this three-dimensional model offers us more methods to monitor and adjust system performances. For instance, if users want c_{ijk} to reach a certain status, they can adjust the control-a_i, research object-b_j, or pay attention to the relations between parameter-c_k. In a similar way, the three-dimensional model will help users find the reasons causing c_{ijk} to arrive at a status, or the possible results if c_{ijk} changed from three dimensions. That is, the three-dimensional model helps users to realize analyzing, controlling and decision-making from three dimensions.

Furthermore, the model is a fourfold-layer model. In other words, besides taking the most simple and pivotal actions with the help of the core growth engine, managers can do research into the sub-growth engines, the balancing loops, or the parameter connections in a lower layer. More deeply, they can also choose two of the three dimensions to do more specific studies, even the three together to analyze $i \times j \times k$ different objects separately.

3. Case Study to an Enterprise

As mentioned in the introduction of this paper, enterprise managers are facing the problem of how to construct comprehensive reliable models. This chapter will take the example of an ordinary manufacturing enterprise to illustrate the three-dimensional ST method.

3.1 The core growth engine (on the top layer)

Managers always regard payments and gains as the most important indicators, which can be chosen to compose the most original and basic core growth engine of enterprises. As shown in Fig.5.1, gains will grow with payments, while more gains would cause payments to increase. The former relation always occurs with some delays (presented in Fig.5.2), due to a balancing loop that takes payments as input and gains as output, as explained in Fig.5.3.

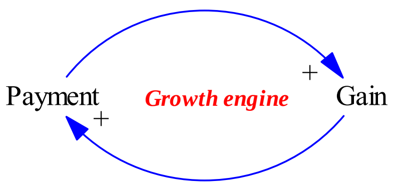

Fig.5.1. Basic engine (1)

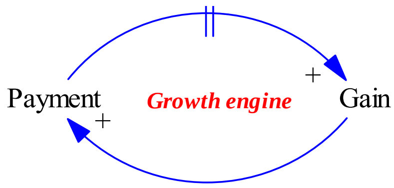

Fig.5.2. Basic engine (2)

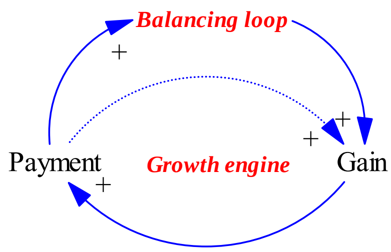

Fig.5.3 Basic engine (3)

Enterprises always categorize their inputs into three sorts: financial inputs, human inputs and material inputs. The first one indicates the investment, distribution and use of funds, including the costs supporting basic operations and expenses paid to relative managements. The second one implies the employment and assignment of employees, involving staff number, capacity and satisfaction, etc. The last one means the purchase, allocation and management concerning materials, related to quantities, qualities and so on. Actually, the latter two are closely related with the funds invested in human and material affairs, to the extent that they could be represented by financial inputs.

Considering enterprises' short-term and long-term benefit and development, gains can be attributed to profits and markets. The profit, the ultimate short-term goal of enterprises, is an actual financial return. However, the market is a focus of long-term development and industrial influence, appearing as an abstract comprehensive return.

Based on analyses above, financial inputs (also called investments) in payments and profits in gains have something in common in that both of them are related with financial parameters, which support them to replace payments and gains in a practical core growth engine, shown in Fig.6.1. The human and material input will appear as control inputs, while the market would transform into system parameters. Now that there is a balancing loop, a dual-influence from the loop to growth engine must exist, which is separated into a positive one related with costs and expenses, and a negative one linked to revenues. Fig.6.2 illustrates the relationship that as investments grow, costs, expenses and revenues all increase. Only the last one has positive effect on profits, while the other two are negative.

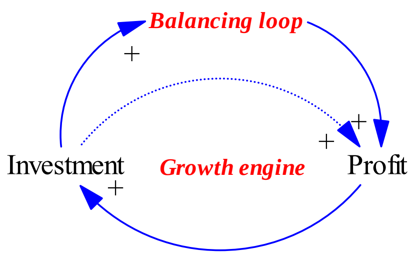

Fig.6.1. Practical engine (1)

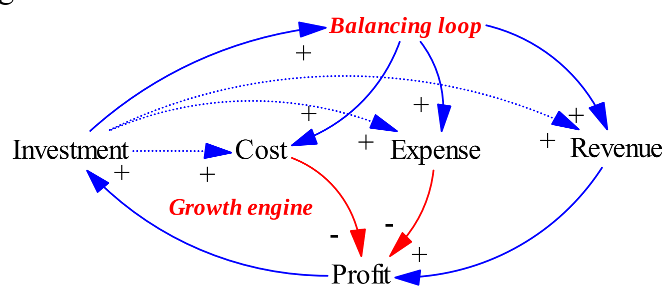

Fig.6.2. Practical engine (2)

3.2 The b_j-engine (on the second layer)

Manufacturing enterprises usually have six such divisions: procurement, production, sales, logistics, finance, and human resources (HR)[19]. Among these six, procurement, production and sales take part in the flows of both funds and materials. More exactly, the ownerships of materials, semi-finished products and finished products can be transferred from procurement to production, then to sales with some domestic transfer prices. Therefore, they all belong to the profit division, which is independently responsible for it no matter if it pays off or loses money. Consequently, they are three independent entities, which represent three functional parts of the enterprise. Compared with them, logistics, finance and HR are all the cost division for assisting operations. However, for that logistics (including inventory and transport) always deals with materials, semi-finished products and finished products, although belonging to the cost division, it is still an independent entity representing a functional segment in the enterprise. Finance and HR are real assistant departments to help every division doing daily works, so they will appear in other places of the model (HR in controls and finance in performances). These relations are illustrated in Fig.7, in which the red arrows represent capital flows.

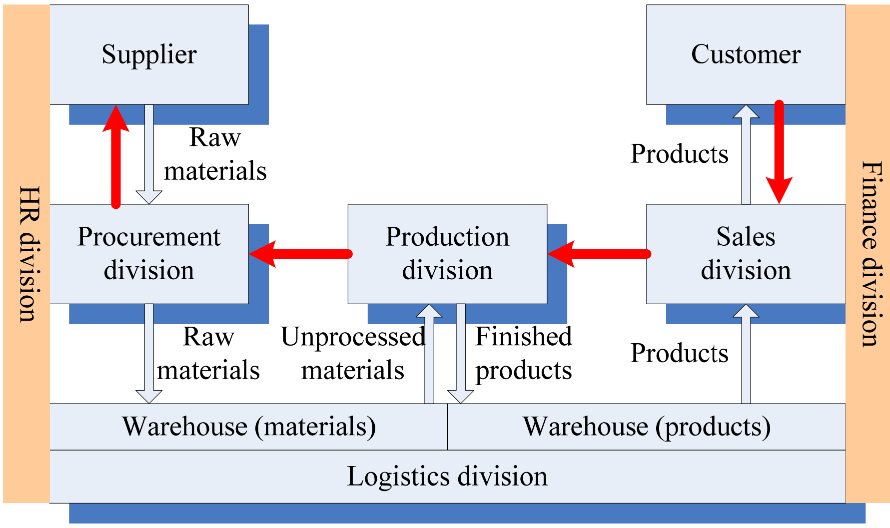

Fig.7. Domestic relations in a manufacturing enterprise

Therefore, the objects set B could be expressed by {procurement, production, logistics, sales}, which can describe a manufacturing enterprise completely and independently. Fig.8 shows the core growth engine and every b_j-engine (sub-engines). Variables underlined imply that their values can be set by users.

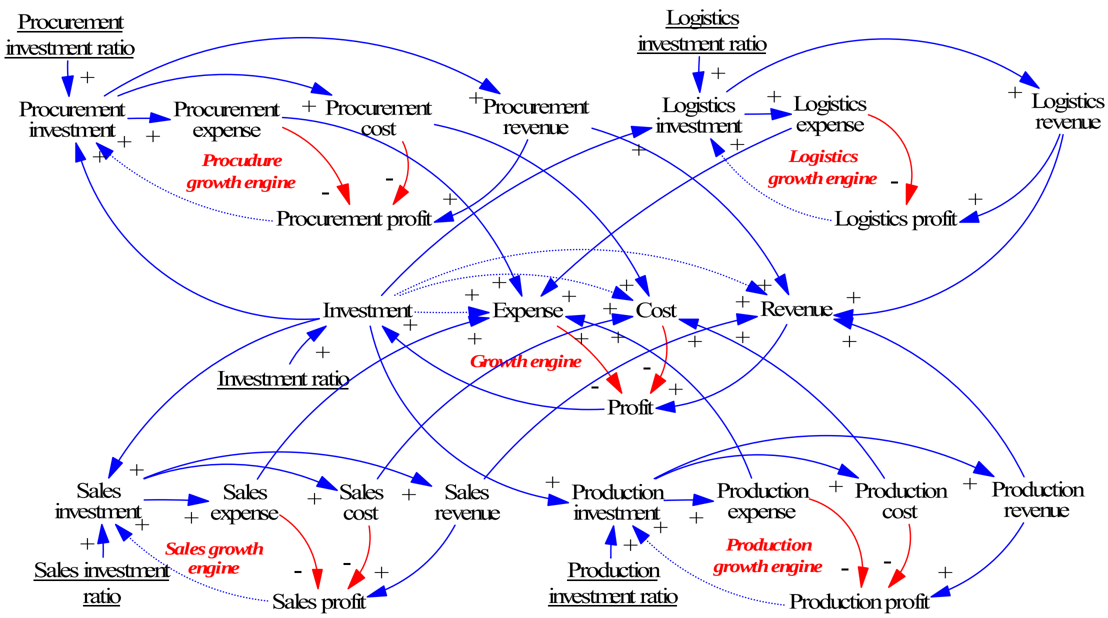

Fig.8. b_j-engines

3.3 The a_i-loop (on the second layer)

As explained above, enterprises have three kinds of inputs: human inputs, material inputs and financial inputs. Now that the last one can represent the other two, and all parameters in the core growth engine are financial indicators, different controls should be led by the funds invested into corresponding control aspects, and the control system would be constructed into a fund-oriented one. It means that the control set A could be {human-ware, material-ware, operating-ware}. Therein, human-ware and material-ware inputs separately represent investments (financial inputs) on employees and equipments, while other financial inputs could be ascribed to operating inputs. Obviously, the three modules are complete together and independent of each other. By doing this, managers can distribute funds through several investment ratios, so as to realize the control to every part of the system. The a_1-loop (human-loop), a_2-loop (material-loop) and a_3-loop (operating-loop) are shown, respectively, in Fig.9, Fig.10 and Fig.11.

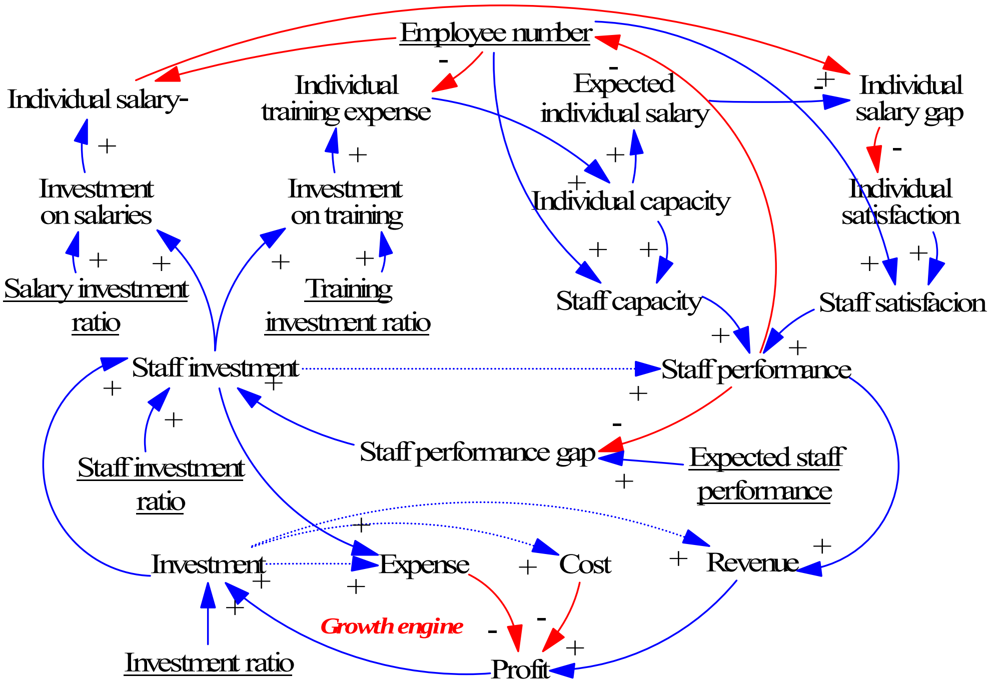

Fig.9. a_1(human-ware)-loop

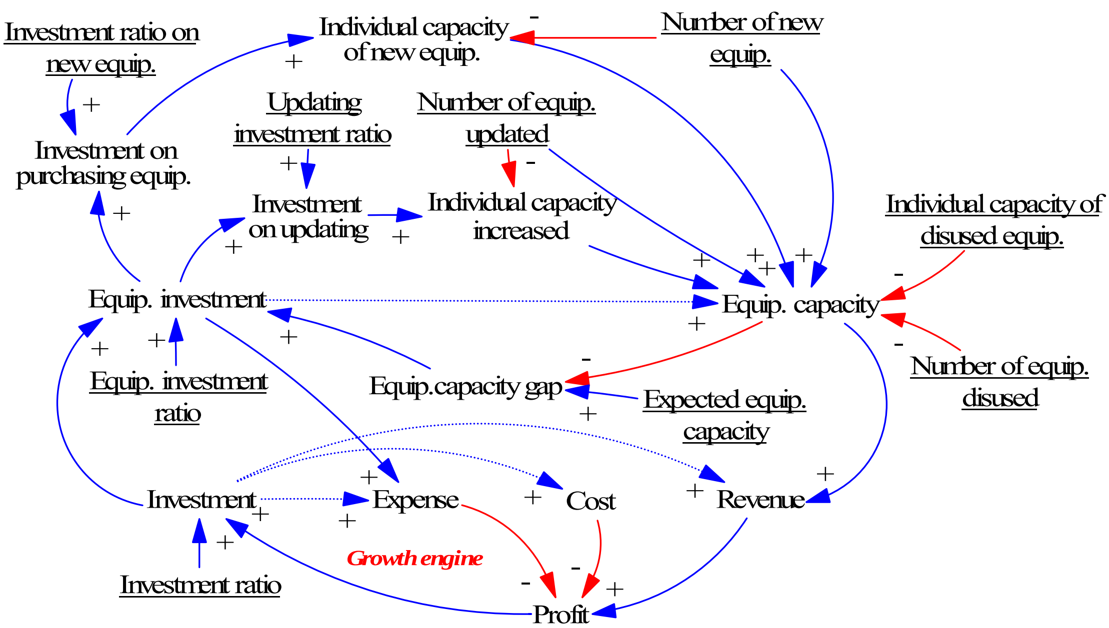

Fig.10. a_2(material-ware)-loop

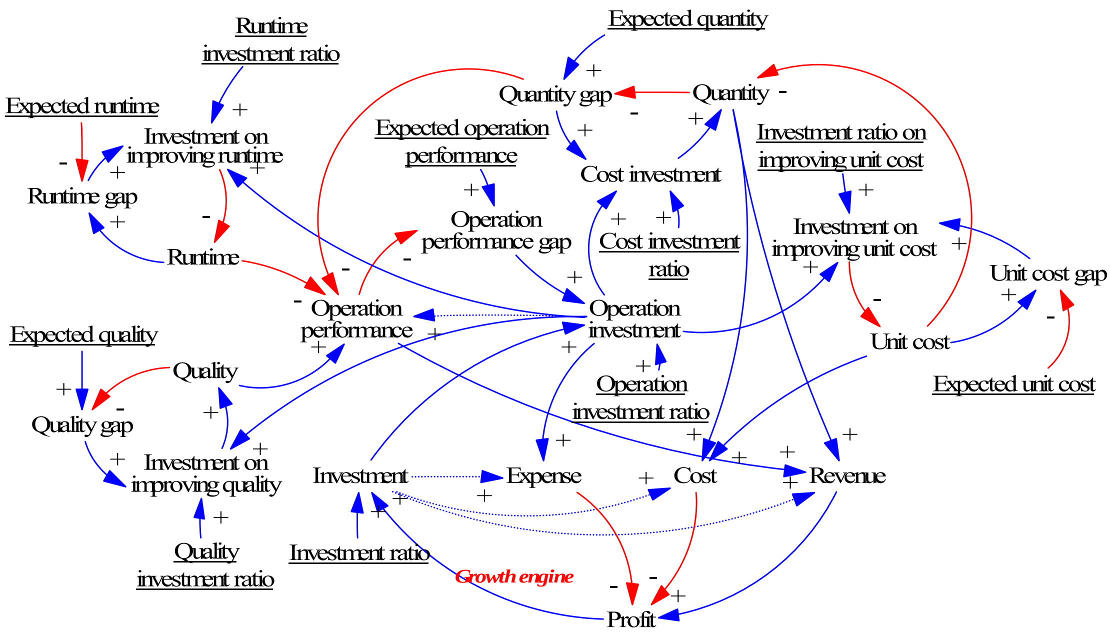

Fig.11. a_3(operating-ware)-loop

3.4 The c_k-connection (on the second layer)

Performances of an enterprise are mainly measured by efficiencies. Generally, manufacturing enterprises have such four kinds of efficiencies: completing rates, passing rates, punctual rates and capital savings rates[19], which respectively correspond with four types of parameters: quantity, quality, time and money. Thus, the parameter set C is designed to be {quantity, quality, time, money}.

Enterprises generally operate on two levels (the planning level and executing level) as well as in two modes (the push mode and pull mode)[18]. Fig.12 shows both levels and modes. On the planning level, relations between variables with prefixes such as expected, planned or predicted reflect the planning process. While on the executing level, actual executing quantities are connected with each other through another line. In push mode, the planning variables are all predicted by enterprises, while they reflect the customer orders in pull mode.

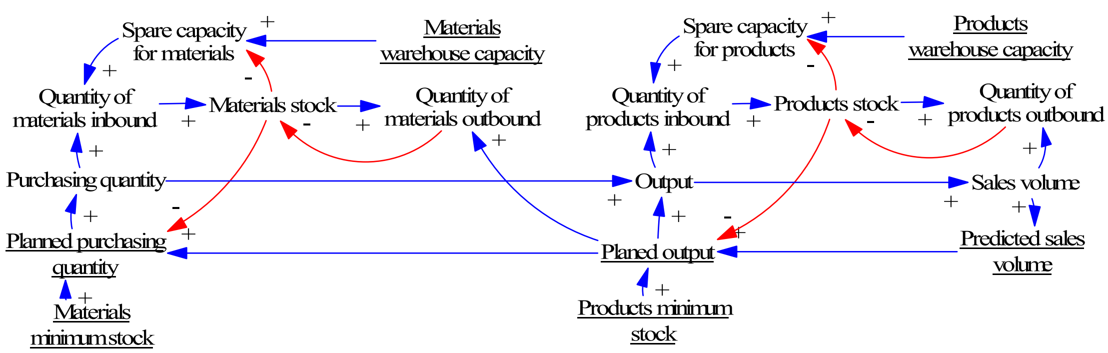

Fig.12. c_1(quantity)-connection

Due to logistics, raw materials just purchased from suppliers are always different from the unprocessed materials outbound to the production departments. In addition, finished-products just produced in plants are generally different from the products sold to customers. Therefore, relations between expected quantity levels reflecting the planning process and between various quantities revealing the executing course can form many loops, as shown in Fig.13.

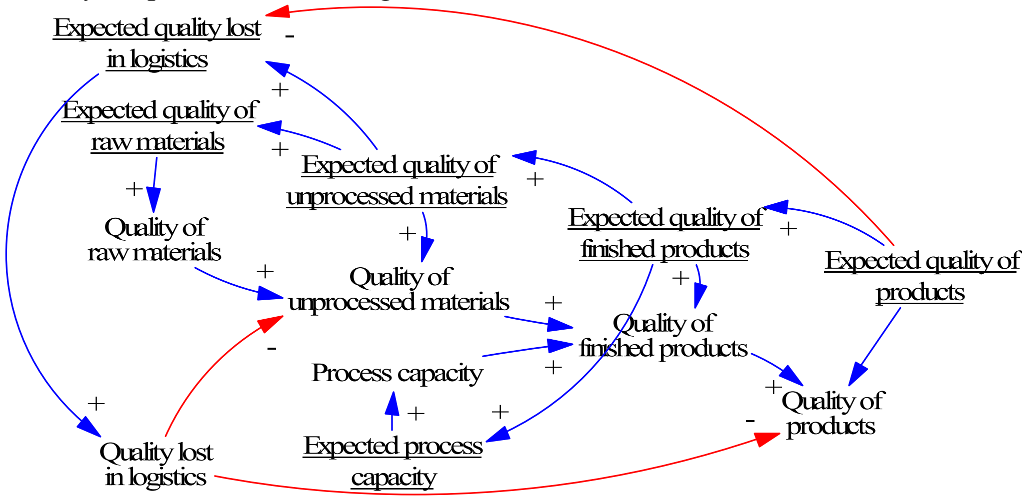

Fig.13. c_2(quality)-connection

Time variables are cumulated as Fig.14 shows. In push mode, on planning level, the expected executing cycle proposes requirements to expected execution times of every segment revolved, while in executing level, these execution times accumulate to the actual executing cycle. While in pull mode, the executing cycle is the maximum of the order cycle time, while others do not change.

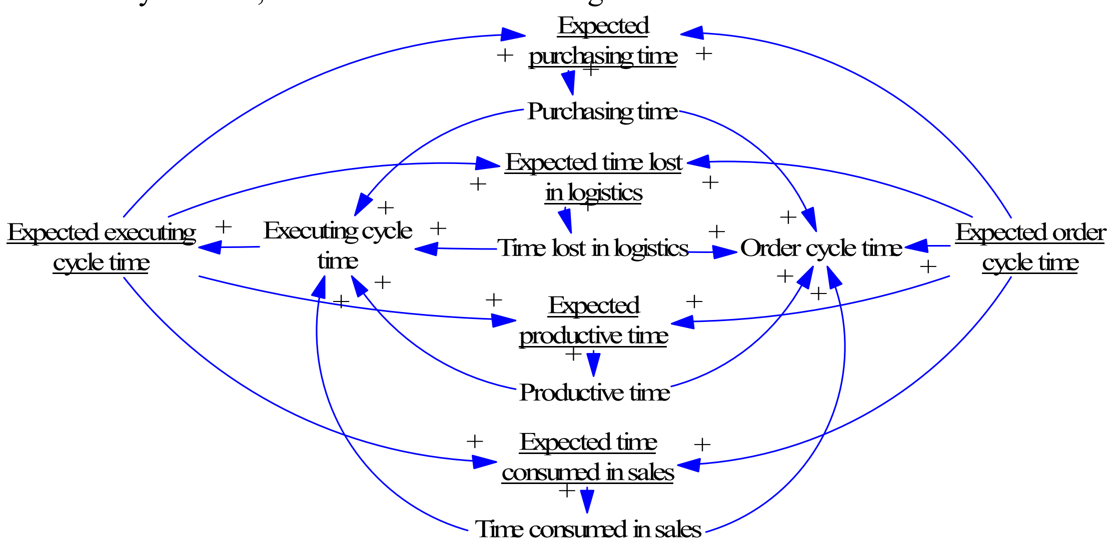

Fig.14. c_3(time)-connection

Circulations of capitals are revealed in Fig.15, in which the procurement division sells unprocessed materials to the production, and the latter then sell them to the sales. Fig.15 shows the circumstance under which the procurement dominates materials stock, the sales controls products stock, and the production only produces products. Particularly, the logistics merely takes charge of goods, and earns from inventory and transport, without referring to affairs of the goods.

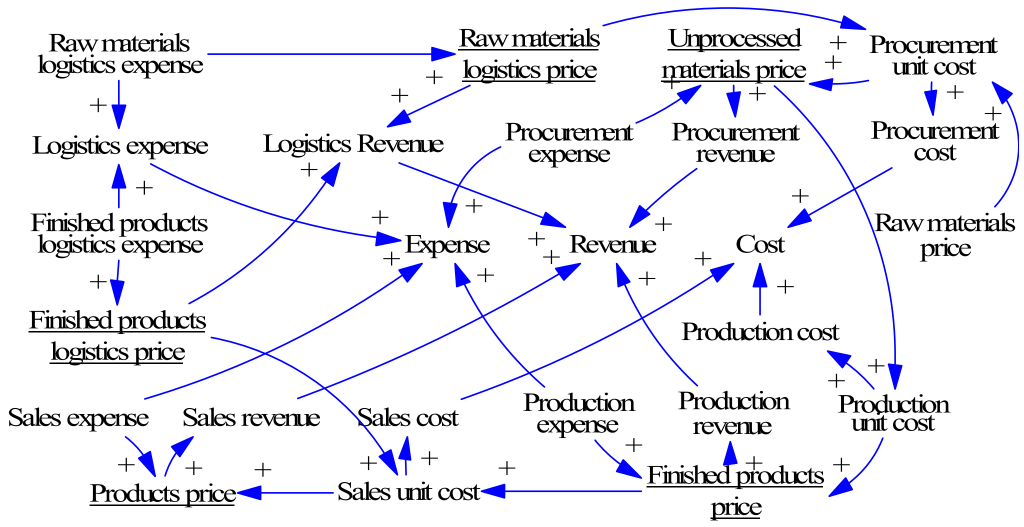

Fig.15. c_4(money)-connection

3.5 More models (on the third and fourth layers)

Except the core growth engine, all above are referring to models on the second layer. There are more models on lower layers. Fig.16 describes the b_2-engine (production-engine) and a_{12}-loop (production human-loop), a_{22}-loop (production material-loop), a_{32}-loop (production operating-loop). Fig.17 presents the b_1-engine (procurement-engine), a_{i2}-loops and performances c_{i1k} (i = 1, 2, 3 respectively represents human inputs, material inputs and operating inputs; k = 1, 2, 3, 4 means quantity, quality, time, money).

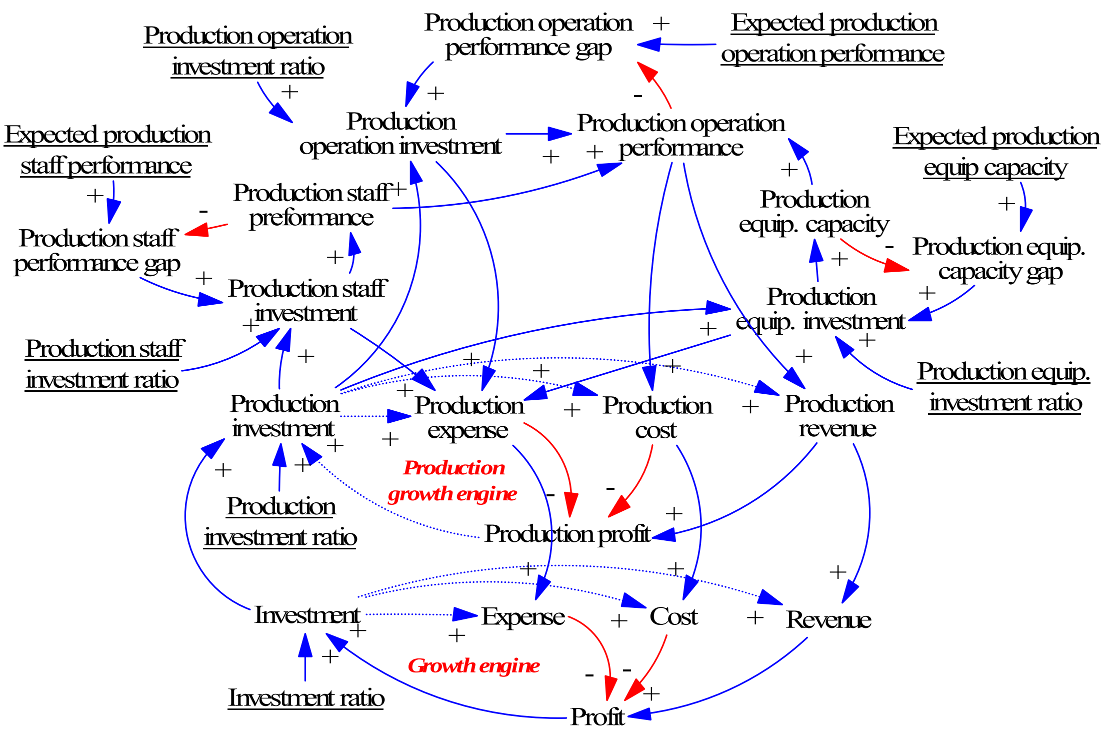

Fig.16. b_2(production)-engine and a_{12}, a_{22}, a_{32}-loop

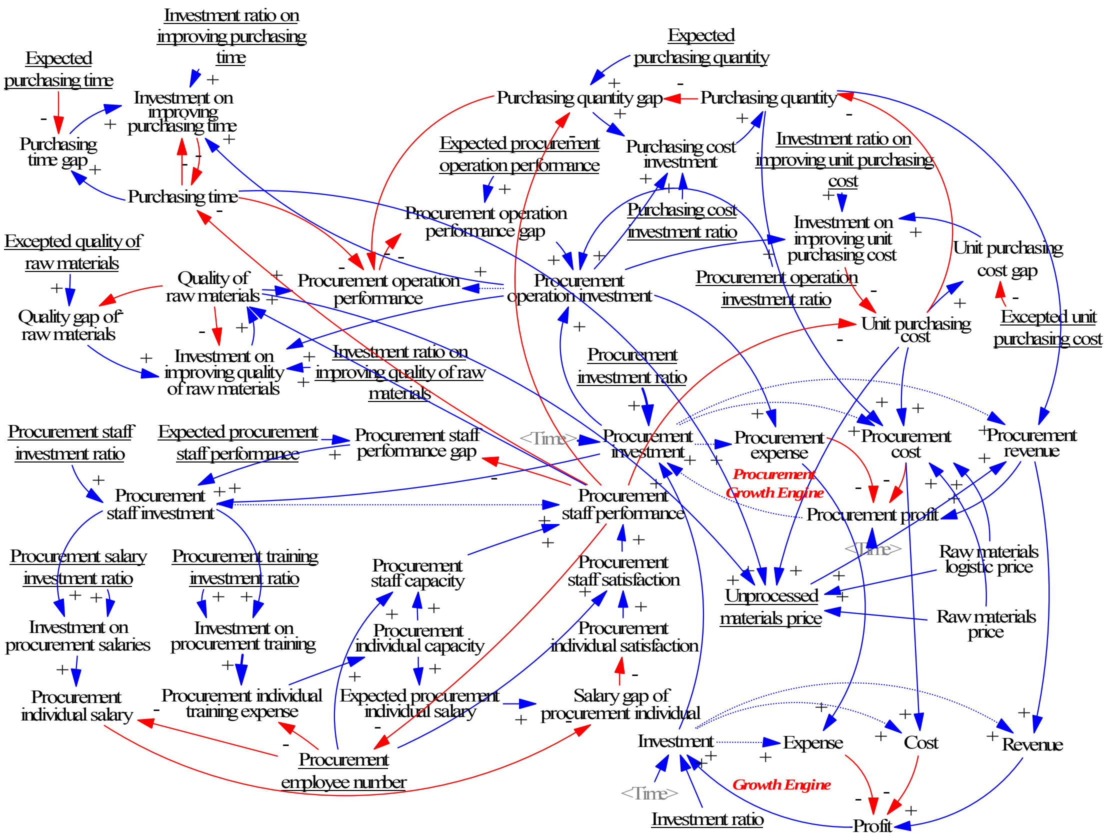

Fig.17. b_1(procurement)-engine, a_{i2}-loops and performances c_{i1k}

When using the three-dimensional ST method to establish models, designers must ensure that the elements describe their sets independently and completely. Taking the business enterprise in this chapter as an example, financial variables must play an important part in operating process. Choosing a funds-oriented control set is reasonable, and the set {human input, material input, operating input} accords with the requests on independency and completeness. Meanwhile, the reliability of the object set {procurement, logistics, production, sales} is determined by the function of manufacturing enterprise departments. In addition, in terms of manufactories' ordinary performance indicator (the efficiency), variables related with the four sorts of efficiencies separately form a performance set containing four elements {quantity, quality, time money}.

4. Conclusion

In order to solve the problem of seeking a comprehensive and objective method to construct the causal model of a system, this paper proposes a three-dimensional ST thought. This method not only adopts the essential thoughts of ST to consider the system as a whole and integrate controls into the causal model, but also makes improvements in objectivity, depth and dimensionality. By analyzing the relationship of the input, system and output, and extending them to system controls, objects and performances, the scopes of modeling are specified. Consequently, the objectivity and reliability of models are guaranteed, while the variability and incertitude are weakened.

Additionally, it offers enough agility to satisfy diverse requirements due to different user preferences. Although the general scopes have been determined, the exact contents of each aspect are flexible. By dividing all elements into three categories, users can not only establish a comprehensive three-dimensional model, but also perform research following their special customs.

Another visible advantage is that it enlarges the viewpoint of designers and managers. Through considering and studying the system from different aspects, the cognition becomes more intensive, and the thought becomes multidimensional, due to the extending on depth and dimensionality.

However, the study is just a qualitative way to start studying a dynamic complex system. Based on a comprehensive cognition to the system, more quantitative analyses such as System Dynamics, Data Mining, and Regression Analysis are needed to realize real simulations.

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