A Research on Systems Thinking Based on Three Dimensions Thought

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【Abstract】

Nowadays, the performance measurement system has developed into a rather advanced extent. But the mature method to analyze the relations between performance measures which play important roles in managements is still in demand. After reviewing relevant researches, on the basis of Systems Thinking, this paper proposes a three-dimensional Systems Thinking method which not only adopts the essential thoughts of Systems Thinking but also extends them to realize better analyzing, controlling and decision-making. Firstly, this paper proves the rationality of the three-dimensional thought and provides modelling method in theory, and then takes a manufacturing enterprise as an example to illustrate the implementation in practice.

【Key words】

Systems thinking, three dimensions, performance measure, causal relation

1. Introduction

Due to the inconstancy of market circumstances and diversity of customer requirements, enterprises are operating with more and more continuous and rapid variations, in order to catch up with the dynamic business world[1]. More exactly, managers always use plentiful 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 the system performances would get continuous improvement[1]. At present, managers generally supervise their enterprises and acquire reliable decision supports through relevant performance measurement systems[2, 3].

Many researchers have been studying on performance measurement systems for a long time and 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 propounded a BSC supply chain performance measurement system[6]. While 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 his 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 Jia-zhen[9], Andersson[10], Cooke[11]) and some commonly used methods analyzing variables such as the Key Performance Indicators-method and the Benchmarking-method also contribute different cognitions and thoughts to researches.

Whereas, only mature performance measurement system is not enough for assisting management. On the one hand, when choosing performance measures, people are always considering the completeness and orthogonality. That is, they want the indicators chosen can completely describe their actual system without overlapping. However, most choices are made only according to some guiding principles and reference models, and need to meet 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 necessary parameters can be recognized by analyzing relations between the former variables[3]. Therefore, seeking these causal links will facilitate people continuously improve their performance measurement systems.

On the other hand, huge amounts of practices have shown that managers are always confused with such problems: 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 care usually vary with time, and are always related to or acting on each other. Actually, lots of complex phenomena are resulted in 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 would 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 starving for a method with relative tools to help them analyze their system which is full of correlations, and offer them decision supports.

At present, researches on indicators and their causal relations are insufficient, with relative theories just at the beginning stage[3, 15]. Currently, the Cognitive Map[15], Strategy Map[16] and Causal Loop Diagrams[3] coming from System Dynamics are all used to solve this kind of problems. Among them, the Systems Thinking[17] (ST), which considers the system and makes causal relation models from a holistic view, is more comprehensive and appropriate. It helps people monitor and adjust their systems through the connection of *levers → balancing loops → driving factors → business growth engine*, and allows farther simulations on computers. But ST models rely on the subjective cognitions and experiences of designers too much. 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 find a way to make comprehensive models with more objectivity is the main problem this paper needs to solve.

2. The Three-Dimensional Systems Thinking

(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_0', a_1', …, a_m') is m-dimensional ($m \geq 1$), B = (b_0', b_1', …, b_n') is n-dimensional ($n \geq 1$), C = (c_0', c_1', …, c_p') is p-dimensional ($p \geq 1$), this thought can be shown as Fig.1.

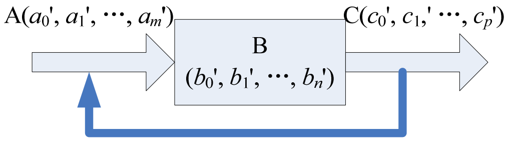

Fig.1. System description

The input can also be taken for control input, system for controlled object, and output for performance output. Considering that the input is m-dimensional, there must exist m independent controls a_0, a_1, …, a_m, which can completely represent all controls without redundancy. Choose such an A = {a_0, a_1, …, a_m} as a control set. In the similar way, the object set B = {b_0, b_1, …, b_n} and performance set C = {c_0, c_1, …, c_p} which can be completely described without overlapping could also be constructed.

In terms of the above definitions, A, B, C could be respectively considered as three dimensions to learn a system. That is to say, (a_0, a_1, …, a_m), (b_0, b_1, …, b_n), and (c_0, c_1, …, 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 ($1 \leq i \leq m$, $1 \leq j \leq n$, $k = 1, 2, …, p$). For example, assuming that $i = 1$ and $j = 1$, if the cubes whose B-coordinate is b_1 are blue, coloring those whose coordinate on A-axis is a_1 with yellow, then there will be p cubes appearing green, just as Fig.2 presents. But actually, it is rarely that every a_i can directly act on each b_j. In this case, if define their influence on c_k's relative element to be zero ($1 \leq i \leq m$, $1 \leq j \leq n$, $k = 1, 2, …, p$), the model still works. Similarly, to deal with the circumstance that c_k have 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.

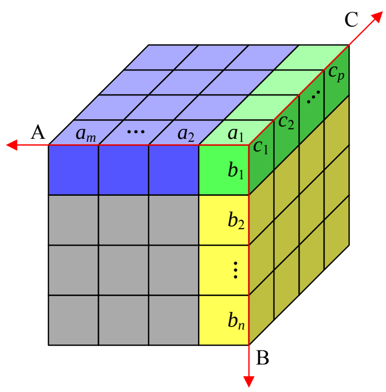

Fig.2. Three-dimensional model of system

This thought can be used for setting models to any entity which 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, and then obtain experience, knowledge and satisfaction. Thus a model as follow can describe the student.

A = {time, energy, money, ...}

B = {study, social work, entertainment, …}

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.

A = {human input, material input, operating input}

B = {procurement, production, logistics, sales}

C = {quantity, quality, time, money}

(2) The three-dimensional model of Systems Thinking

Systems Thinking has given a current business model[17] describing a motivated entity, as shown in Fig.3. The modelling 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 operating on their corresponding balancing loops in the first place, 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 make an overview to the whole system through the core growth engine, but also offering them more details about the lower layer (the exact loops).

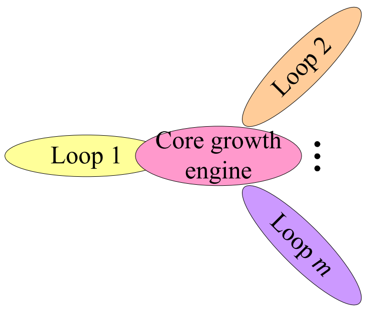

Fig.3. Current business model of Systems Thinking

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

i. With 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 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 beween c_{ijk} ($1 \le i \le m$, $1 \le j \le n$), totally named as c_k-connection.

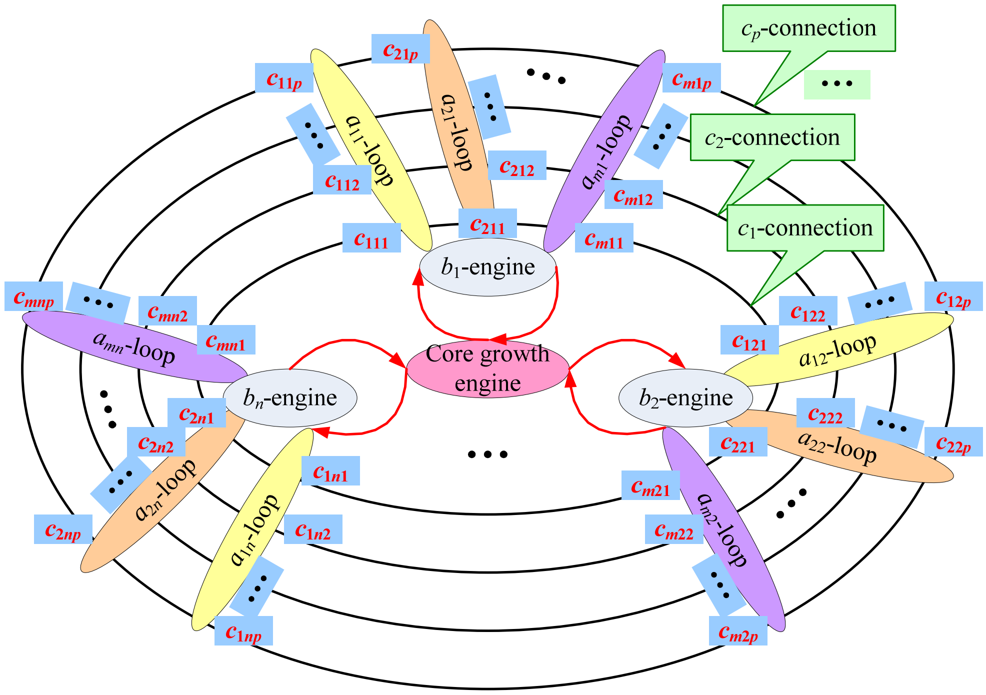

Fig.4. Three-dimensional model of Systems Thinking

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 an instance, if users want c_{ijk} to reach a certain status, they can adjust the control-a_i, research from 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} arriving 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.

Further more, the model is a fourfold-layer one. 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 that how to construct a comprehensive reliable models. This chapter will take the example of an ordinary manufacturing enterprise to illustrate the three-dimensional ST method.

(1) The core growth engine (on the top layer)

Managers 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 increasing. But the former relation always occurs with some delays (presented in Fig.5.2), due to a balancing loop which takes payments as input and gains as output, as explained in Fig.5.3.

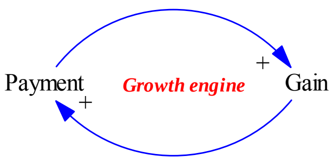

Fig.5.1. Basic engine(1)

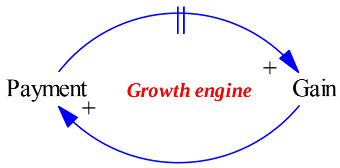

Fig.5.2. Basic engine(2)

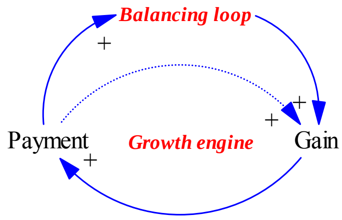

Fig.5.3 Basic engine(3)

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 affairs about the 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 enterprises pursue, 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 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. As to others, 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 relations that as investments grow, costs, expenses and revenues all increase, but only the last one has positive effect on profits, while the other two are negative.

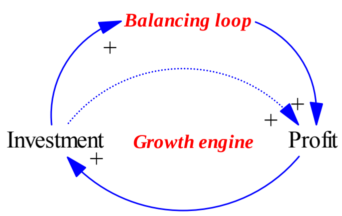

Fig.6.1. Practical engine(1)

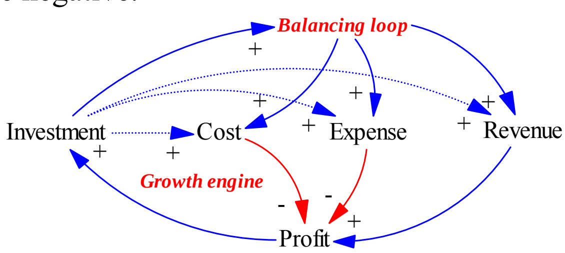

Fig.6.2. Practical engine(2)

(2) The b_j-engine (on the second layer)

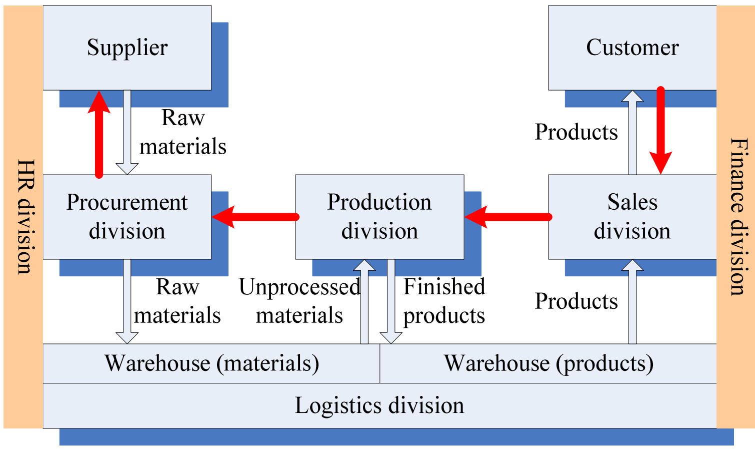

Fig.7. Domestic relations in a manufacturing enterprise

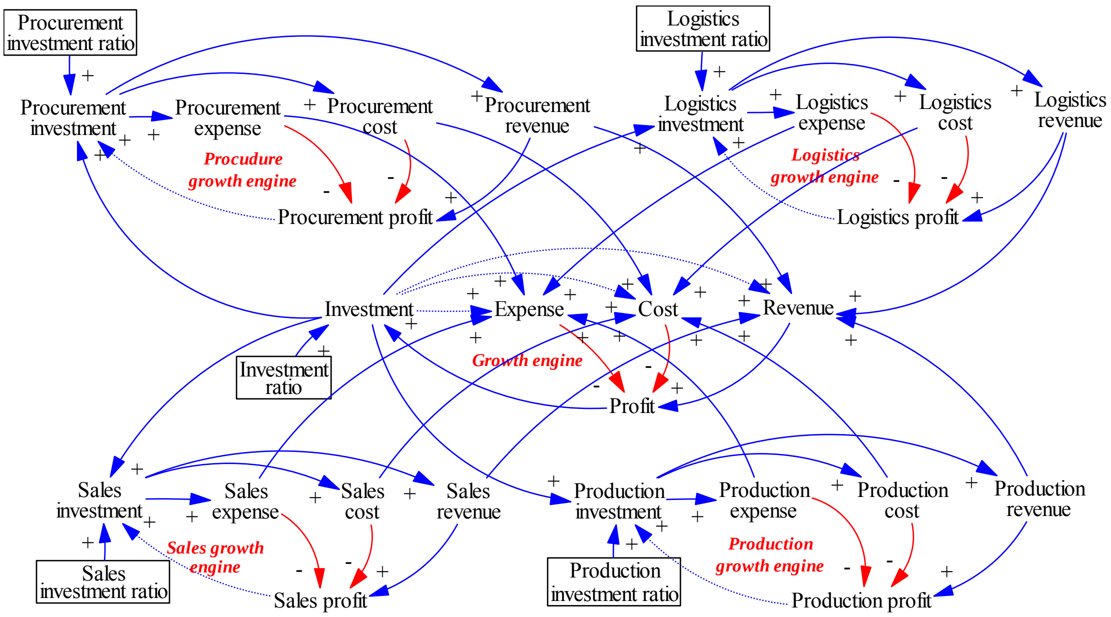

Fig.8. The b_j-engines

Manufacturing enterprises usually have such six divisions: the procurement, production, sales, logistics, finance, and human resources (HR) division[18]. Among these six, the procurement, production and sales are taking 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 the procurement to production, then to sales with some domestic transfer prices. Therefore they all belong to profit division, which is independently responsible for itself no matter it pays off or loses money. Consequently, they are three independent entities, which represent three functional parts of the enterprise. Compared with them, the logistics, finance and HR are all cost division for assisting operations. However, for that the logistics division including inventory and transport always deals with materials, semi-finished products and finished products, although belonging to cost division, it is still an independent entity representing a functional segment in the enterprise. While the finance and HR are real assistant department 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.

Therefore, the object 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-engine). Variables in the box imply that their values can be set by users.

(3) The a_i-loop (on the second layer)

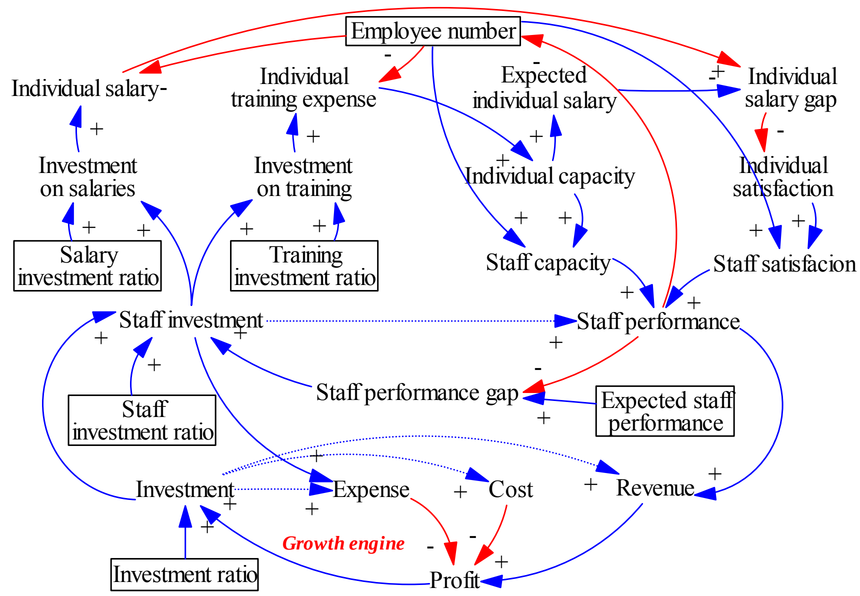

Fig.9. The a_1(human)-loop

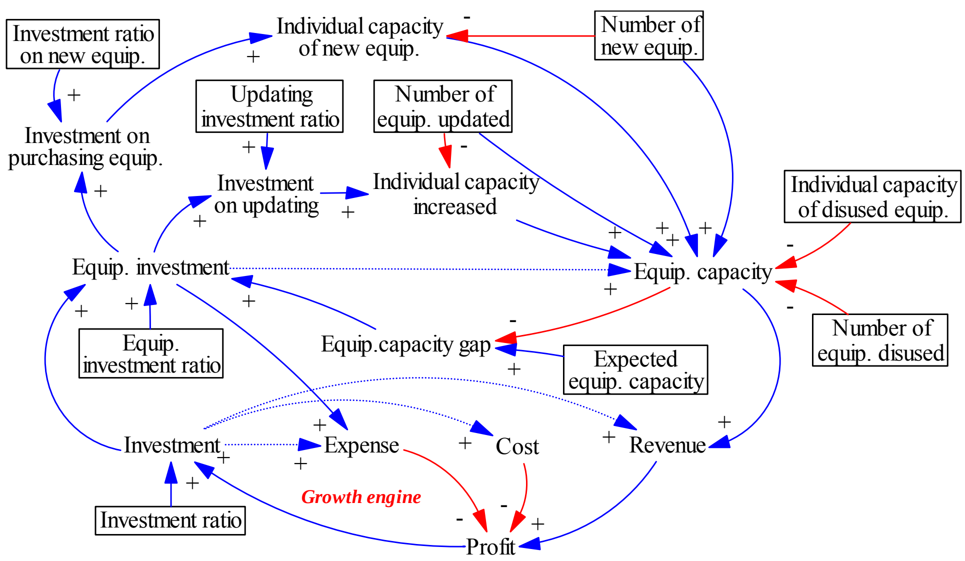

Fig.10. The a_2(material)-loop

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 input, material input, operating input}, thereinto human and material 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 to each other. And by doing this, managers can distribute funds through several investment ratios, so as to realize the control to every tiny part of the system. The a_1-loop (human-loop), a_2-loop (material-loop) and a_3-loop (operating-loop) are respectively shown in Fig.9, Fig.10 and Fig.11.

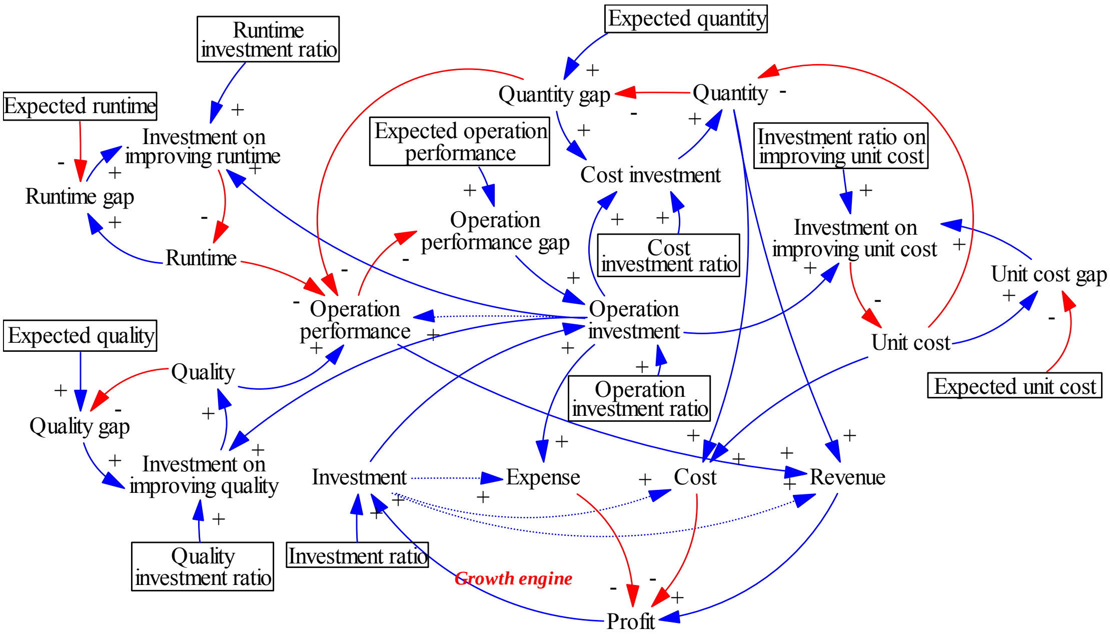

Fig.11. The a_3(operating)-loop

(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: the quantity, quality, time and money. Thus the parameter set C is designed to be {quantity, quality, time, money}.

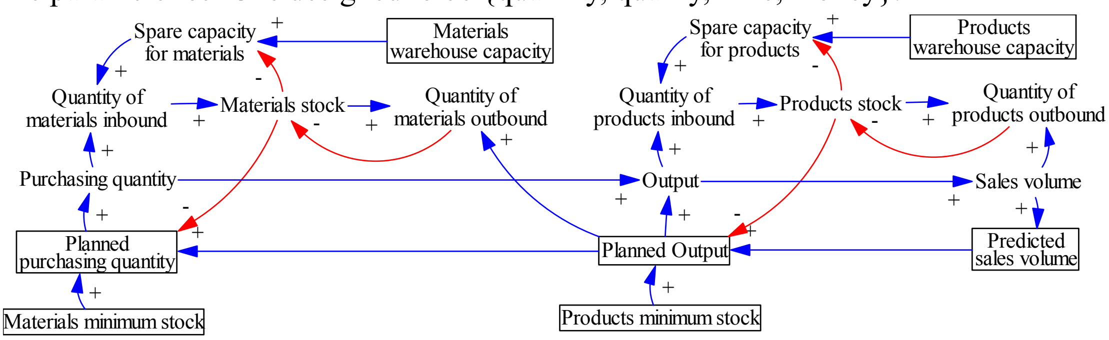

Fig.12. The c_1-(quantity)connection

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 planning level, relations between variables with prefixes such as expected, planned or predicted reflect the planning process. While on 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.

Due to the logistics, raw materials just purchased from suppliers are always different from the unprocessed materials outbound to the production departments. And also, 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.

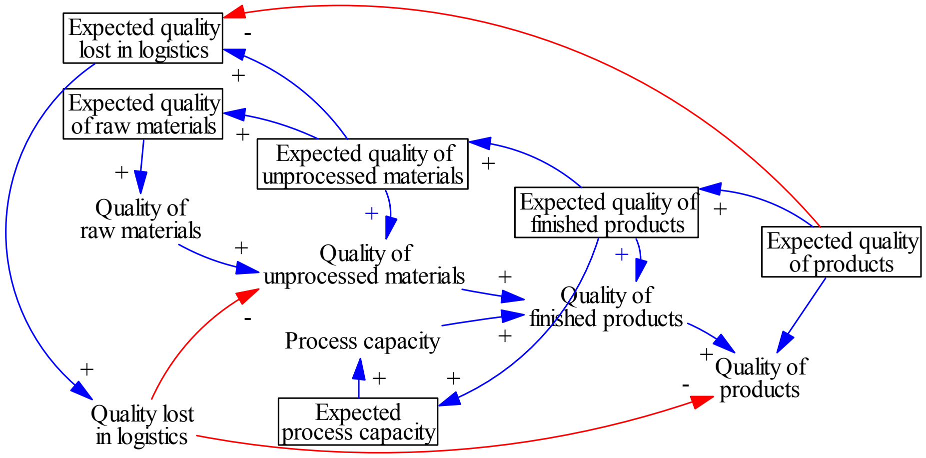

Fig.13. The c_2-(quality)connection

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, others do not change.

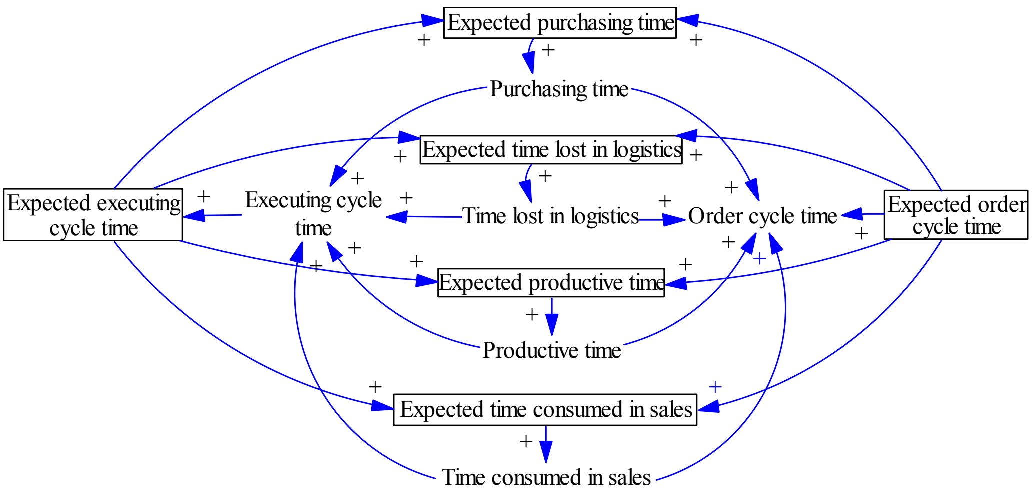

Fig.14. The c_3-(time)connection

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 of that 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.

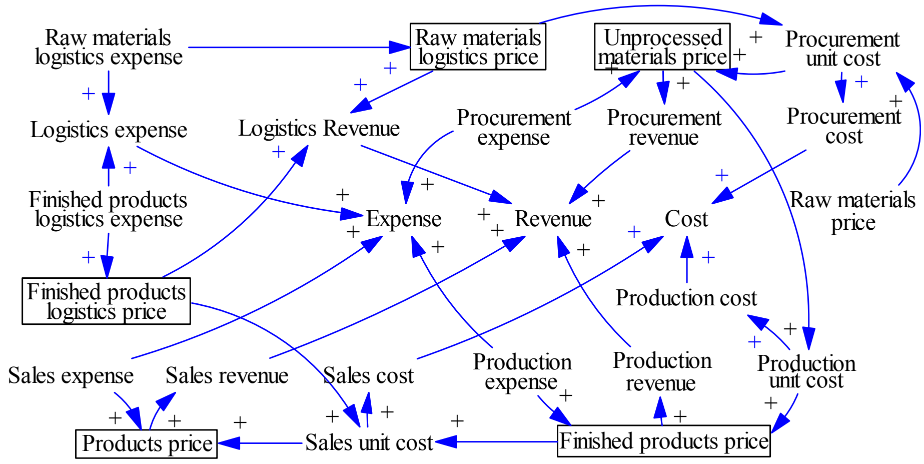

Fig.15. The c_4-(money)connection

(5) More models (on the third and fourth layers)

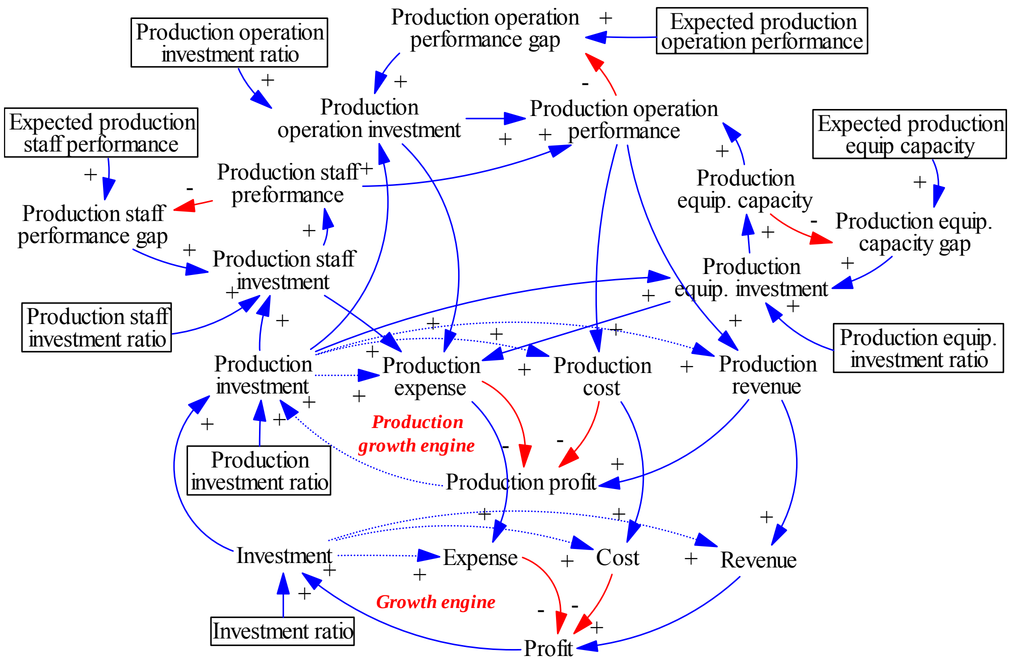

Fig.16. The b_2(production)-engine and a_{12}, a_{22}, a_{32}-loop

Except the core growth engine, all above are referring 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).

When using the three-dimensional Systems Thinking method to establish models, designers must ensure that the elements should describe their sets independently and completely. Taking the business enterprise in this chapter as an example, financial variables must take an important part in operating process. So 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 containning four elements {quantity, quality, time money}.

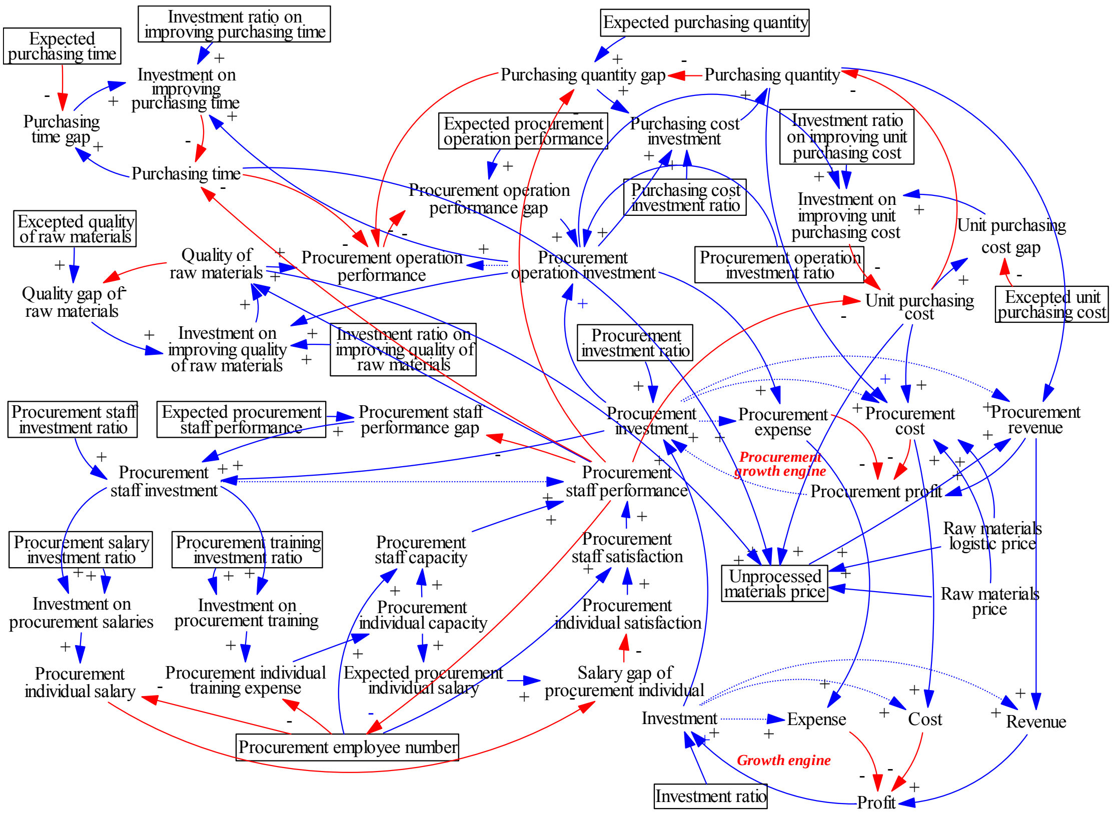

Fig.17. The b_1(procurement)-engine, a_{i2}-loops and performances c_{i1k}

4. Conclusion

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

Meanwhile, 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 make researches following their special customs.

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

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

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