Chapter 2
Versatile Engineering

Shuichi Fukuda

Abstract It is pointed out in Chap. 1 that to cope with the rapidly progressing diversification and frequent and extensive changes, we need to move from theoretically rational engineering to value rational engineering. In this chapter, we discuss what are needed to step forward towards this direction. Three major points are taken up: ambience, modularization and resilience. We have been paying most of our efforts to develop excellent functions for specific purposes. But it is impossible to take care of individual needs this way. Ambience is one possible solution. Just as we find a personally comfortable spot under sunlight, we can utilize ambience as we like and as we need. Modularization is attracting wide attention these days, but most of the discussion about it is made from the standpoint of product value. How we can reduce time and cost to produce a product that will meet diversifying needs or expectations from our customers. But from the point of value rational engineering, modularization is important because it turns processes into value creating activities. Thus, modularization is important in terms of process values for value rational engineering. Zweckrational or theoretical rational engineering shows us a clear-cut path to the goal. But in Wertrational or value rational engineering, we need to go forward by trials and errors. Thus, learning from failures becomes very important in value-oriented engineering. Therefore, the importance of resilience is stressed. In short, the transition from theoretically rational engineering to value-oriented engineering means we have to be more pragmatic in our engineering.

2.1 Introduction

We have discussed in Chap. 1 that it becomes increasingly difficult to cope with the rapidly increasing diversification and to adapt flexibly to the frequent and extensive changes if we stick to the traditional instrumental rationality.

S. Fukuda (✉)
System Design and Management, Keio University, 4-1-1, Hiyoshi, Kohoku-Ku, Yokohama 223-8526, Japan
e-mail: shufukuda@gmail.com

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We have succeeded in expanding controllability beyond the rational world, because we managed to identify feature points in the system, which can be described explicitly.

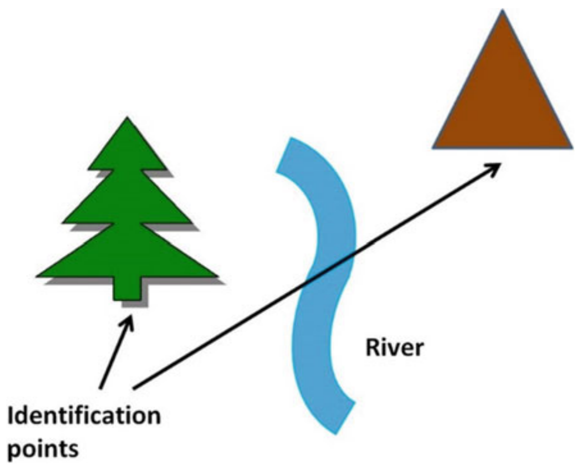
Let us explain by taking an example of identifying the name of a river. A river is always changing. So, if we look at the river itself, we will never be able to identify its name. But if we turn our eyes from the river, and we look around it, we find trees or mountains which do not change. These feature points lead us to the identification of the river (Fig. 2.1).

Let us take arc welding for example. Arc changes its state from gas to liquid and then to solid. There is no single governing equation that describes this state transition. If we could control arc, we could prevent thunder and lightning. There are many researches on arc, but its behaviour cannot be described. So, instead of focusing our attention on molten pool, we look around it and find feature points which can be rationally analysed and controlled. Thus, we can control arc, although we cannot predict its behaviour. Arc welding is, as everybody knows, used in many engineering structures. Engineering expanded its controllability this way. We were very clever so we could rationalize the system, although it involves such elements which do not follow rational rules. To put it another way, we succeeded in expanding explicit knowledge, beyond the rational world.

But environments and situations are quickly changing. They change more frequently and extensively and the nature of the change itself has changed. Changes yesterday were smooth so that they could be differentiated. Therefore, we could predict the future. But today changes are so sharp, and we cannot differentiate them. It means theoretically speaking we cannot predict the future (Fig. 2.2).

Michael Polanyi [1] pointed out that there are two kinds of knowledge: explicit and tacit. Explicit knowledge can be verbalized or can be expressed by equations. But tacit knowledge cannot. What traditional engineering pursued was how we can expand explicit knowledge world. Our challenges were successful until today.

Fig. 2.1 Identification points



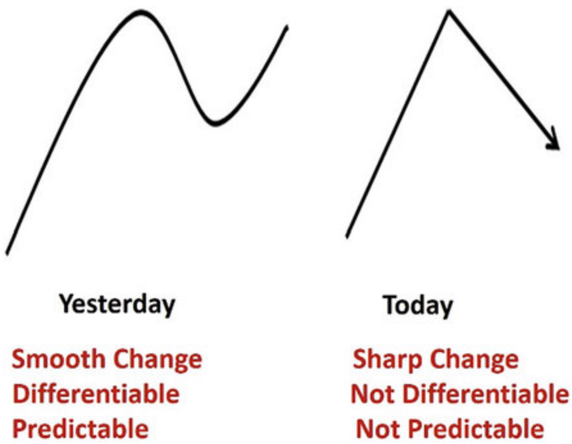


Fig. 2.2 Changes of yesterday and today

But today, environments and situations change so frequently and extensively and we cannot find controllable feature points.

Bicycle riding is often taken up as an example of tacit knowledge. But in the case of bicycle riding, we still can manage to find feature points around us, although it is not easy.

But if it comes to swimming, water is always changing so we cannot find any feature points around us anymore. We have no other choice but to rely on our own sense of balancing or proprioception [2].

Until now, we have been observing the system from outside and identify the system and its controlling parameters. But this approach does not work in the case of swimming. We cannot identify the system and its controlling parameters at all, if we observe it from outside. We should be in the system or in the flow and learn how we can do the job. That is engineering tomorrow.

2.2 Human Motion Control

We have taken up swimming as an example of tacit knowledge, which current engineering approach does not work. So, let us first consider how motion control is different between machines and humans. As Nikolai Bernstein [3] pointed out, the difficulty of human motion control is its tremendous large degree of freedom. Figure 2.3 shows Bernstein's cyclogram. Near the target, human motion trajectories do not change. But apart from the target, human moves in many different ways.

In the case of machines, their trajectories are fixed so the same trajectory is repeated. But in the case of humans, their trajectories vary so extensively from action to action. This may be because they need to balance their bodies before doing the job. Therefore, it may not be too much to say that our motion control is just like

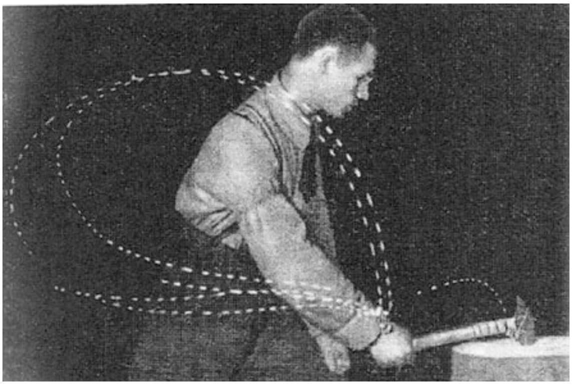


Fig. 2.3 Bernstein's cyclogram

swimming. We do not find feature points to rationalize our motion trajectories, but instead we rely on our own sense of balancing.

To express this in another way, machine motion control is instrumentally rational, but human motion control is value rational. We do not care how we move, and we do not mind whether we can reproduce our behaviour. What we do care is whether we can hit the target or not, or in swimming, we can swim or not. We do not mind how beautiful we can behave to do the job. Achieving the goal is our first priority.

Thus, human motion control is goal-oriented. We are interested in what we achieve, not in how we do it. Human motion control is, therefore, a good example of tacit knowledge and value-oriented rationality. Achieving the goal means value. How we can get to the goal does not count much.

2.3 How Can We Move Towards Value Rational Engineering?

As pointed out many times, it is imminent for us to move towards value rational engineering beyond instrumentally rational engineering to expand our engineering in order to adapt to the drastically changing world. Let us discuss here how we can.

2.3.1 Ambient Engineering

In 2014, Philips Lighting demonstrated ambient lighting at Frankfurter Messe. This surprised many people, including lighting designers. Until then, lighting has been considered as a tool to achieve a specific purpose. For example, reading lights are developed to assist us to read comfortably and with ease.

But their philosophy is very much different. Let us consider sunlight. Sunlight is shining everywhere, with no specific purpose. It creates ambience. And those who would like to bathe in the sun, they will go out. And those who would like to take a rest in the shadow, they will. Anybody can find a comfortable or a personally valuable spot in the sunlight. What Philips Lighting attempted to do was to provide such ambient lighting.

It must be remembered, however, that the word "ambient lighting" has been used for a long time before this demonstration. In photography, photographers often use ambient light, which is not prepared by them to take photographs. They pick up the spot which appeals to them. Thus, it is a matter of personal perception of the environment. Although the environment is the same, the spots where photographs are taken differ from photographer to photographer. In other words, how the environment is cut out in such a personal frame reflects the personality of a photographer.

These examples teach us a lesson. Even if we cannot develop engineering which can cater to each personal needs, we could develop such ambience. Then, people can find their emotionally satisfying personal space.

In a sense, common platform which is a buzzword today plays the same role. People can utilize the common platform as they like, and if they wish, they can add something, just like we wear accessories, when we dress up. Even if the dress may be the same, you look very much different and you feel different, when you put on different accessories.

2.3.2 Modularization

Another approach would be modularization. This is also attracting wide attention these days. But most of the discussion about modularization is product-focused. We must remember that modularization has another advantage. Please consider Lego. Lego sells only blocks. But people enjoy putting them together to realize something. If we evaluate its value, then cost is minimum and putting them together into an object is great performance. So, its value is extremely high. What Lego taught us is there is another value in addition to product value. It is process value. We, engineers, forgot about process values. We have been paying our primary attention to the value of a final product alone (Fig. 2.4).

Most discussion about modularization is how we can develop a final product with less cost and time, but still it answers to the rapidly diversifying requirements. Very few discussions are made about how it will create process values.

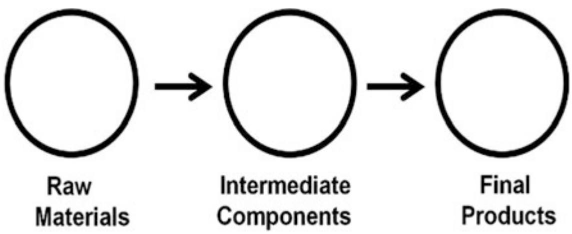
In Japan, flower arrangement and tea ceremonies are very popular. If we would like to enjoy beautiful flower arrangement or tasteful tea, it would be the best to ask experts to prepare them. Why we pay money to learn flower arrangements or tea ceremonies is we would like to enjoy the process. We pay money to the process, not to the final product we make.

Fig. 2.4 Lego blocks

Additive manufacturing and 3D printing (AM3D) are attracting wide attention these days. But again, most of the discussion about them is final product-focused. They discuss how design and manufacturing can be made flexible and with less expertise. They have final product and current industrial framework on their minds. But as such movements as Maker indicate, these new technologies are expected to open door to the new engineering where process values are highly evaluated. People enjoy designing and manufacturing, just as Japanese do in flower arrangements. They are enjoying the process, and processes produce values. The vehicles are now quickly changing into EVs, and if EVs become prevalent, then, we do not need such complicated technologies, which are used in automotive industries today. EVs are modularized, so that many non-experts can design and manufacture. Then, the production of a vehicle itself will produce value. We have to note that the age is moving quickly from product value to process value, and engineering tomorrow must consider how we can produce value through processes.

Modularization is expected to change our engineering from product value-oriented to process value-oriented. And in fact, industry framework itself is expected to change from the current linear final product-based system (Fig. 2.5) to

Fig. 2.5 Current industry framework



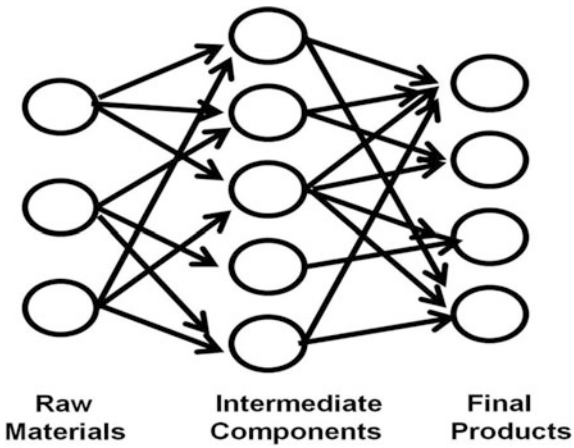


Fig. 2.6 Future industry framework

intermediate component-based industry framework (Fig. 2.6). Then, even if intermediate components are designed and produced by experts, customers can still enjoy putting them together as they like and customize their final products. Thus, final products meet their expectations and they can enjoy the processes as well.

2.3.3 Versatility

As pointed out, industry framework will be changing from the current final product-oriented to the intermediate component-based in order to cope with the frequently and extensively changing environments and situations and to meet the rapidly diversifying requirements and to enhance process values.

To express it another way, traditional industry framework has been tree-structured. But to increase flexibility and adaptability, it must be changed to network-structured (Fig. 2.7). In a tree structure (shown on the left), the output node is only one. Every node works to produce a better output. In traditional engineering, industry is focused on a final product. So, this tree structure works best because the goal is clear so that it will increase efficiency and it is easy to reduce cost.

But to increase flexibility and adaptability, industries have to produce many different products. Thus, a network structure (shown on the right) works best, because any node can be an output node. However, to increase its flexibility and adaptability more, the network needs to be adaptive. It must change its structure from case to case to adapt to the changes.

Knute Rockne, famous American football player and coach, left us the following words, “11 Best, Best 11”. What he meant by this word is “the best team cannot be made up with 11 best players. When 11 players play together as a team, it will become the best team”. And he demonstrated that this is true by bringing up University of Notre Dame to an ever-winning university.

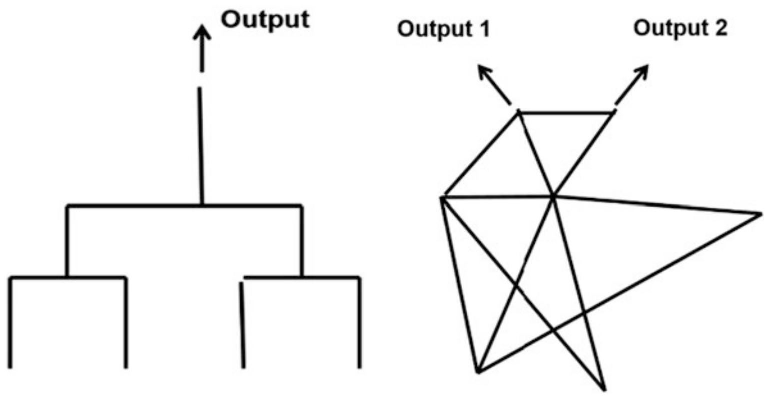


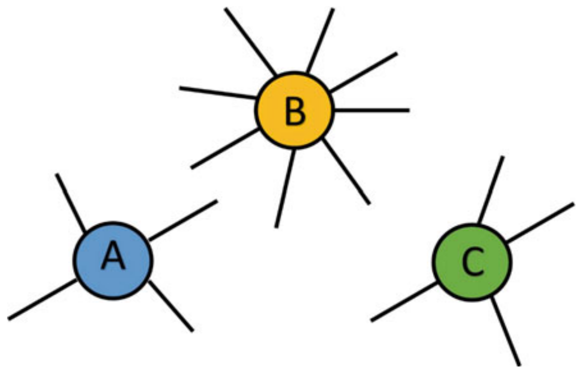
Fig. 2.7 Tree and network

Franz Beckenbauer, famous footballer and manager, also introduced Libero system into soccer. Until then, each soccer player is expected to work best in his own position. But Beckenbauer realized that games come to change so frequently that a team cannot win if they play this way. Players must be more versatile and have to play together flexibly and adaptively as a team. His position was midfielder, and midfielders can see the whole game. They can understand how the game is changing and what formations are needed in the next step. So, he gave instructions or advice to other players how they can fight in another formation. Thus, he was called Der Kaiser. He introduced adaptable team working (network) into soccer.

Industrie 4.0 is attracting wide attention in engineering. This is also a change from 11 Best to Best 11. Until now, Germany is very famous for their excellent Meisters. But today, we need Best 11. So, Germany proposed Industrie 4.0. Its idea is to team up Mittelstand, small- and medium-sized enterprises (SMEs), to increase its global competitiveness. These SMEs may not be the best producer, but if they team up, they can produce best products flexibly and adaptively that meet rapidly diversifying customer expectations.

What is important for Best 11 is versatility. Figure 2.8 represents each SME as a node. What is important for Best 11 SMEs is to have many and different links, such

Fig. 2.8 Versatile node



as shown as B. If each node (each SME) has many different links (different capabilities), then the possibility of teaming up as many different networks grows, so that flexibility and adaptability increase to a large extent.

Thus, versatility is the keyword in the next engineering.

2.3.4 Resilience

Importance of versatility is emphasized. However, resilience is none the less important. Let us get back to the discussion of Zweckrationalitaet and Wertrationalitaet. Zweckrationalitaet is purpose-oriented, and it is means-ends rationality. It provides explanatory reasons or theoretical reasons, or it may be called evidential reasons. Wertrationalitaet, on the other hand, is very much practical. As pointed out earlier, it provides reasons for action, reasons for justifying our actions.

Zweckrationalitaet and Wertrationalitaet may be compared to railroad and voyage (Fig. 2.9).

In the case of railroad, we make decisions before we act and the goal is very clear. We decide which line or which train to take before we get on a train. Thus, means is directly related to the end and the process of getting to the goal is the same, if we select one choice. This is the same as in the case of machine motion.

In the case of voyage, even if we make a very good decision today, the weather might change suddenly tomorrow and the hurricane might be coming our way. Thus, in voyage, you need to set an immediate goal under the current situation and have to move ahead by trials and errors. In other words, we have to learn from failures to get to our final destination. To express it another way, resilience is needed.

In the case of railroad, we may be able to respond to the diversifying requirements, if we prepare many lines and trains. But no matter how many lines or trains we may be able to prepare, it is static. The framework does not change, or it may be called tactical.

In the case of voyage, it is strategic and dynamic. The situations change very frequently and extensively so we cannot prepare any fixed framework for our

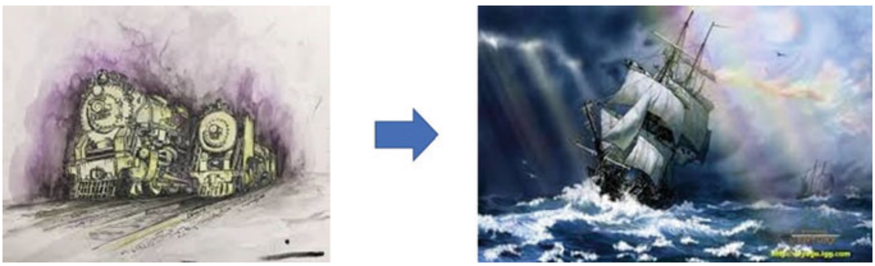


Fig. 2.9 From railroad to voyage

actions. We have to observe the current situations and make decisions to adapt to or overcome the situation to move to the next step.

Railroad represents our traditional engineering, and voyage represents our future engineering. We need more practical or pragmatic engineering. Thus, learning from failures or trials and errors plays a most crucial role in our future engineering.

In our traditional engineering, we just keep on going forward and forward. Then, you can get to the goal faster. But what is called for in our future engineering is how we can go zigzagging but can find the right path to the goal. And there may be many paths. This is what we observe in human motion. Human moves in many different ways, but they know how to balance their bodies and can do the job after all.

Thus, Zweckrationalitaet can be compared to machine motion or railroad, and Wertrationalitaet can be compared to human motion or voyage. We have to remember that Zweckrationalitaet and Wertrationalitaet are deeply related. It may be said that Wertrationalitaet is a balancing of Zweckrationalitaet to respond to the current situation. Balancing is nothing other than resilience.

2.4 Summary

To cope with the rapidly progressing diversification and frequent and extensive changes, we need to move from theoretically rational engineering to value rational engineering.

Ambience, modularization and resilience play important roles for this change.

(1) Ambience

Traditionally, most of our efforts have been paid to develop excellent functions for specific purposes. But it is impossible to take care of individual needs or expectations this way. Ambience is one possible solution.

Just as we find a personally comfortable spot under sunlight, we can utilize ambience as we like and as we need.

(2) Modularization

Modularization is attracting wide attention these days, but most of the discussion about it is made from the standpoint of product value; that is, how we can reduce time and cost to produce a product that will meet diversifying needs or expectations. But from the point of value rational engineering, modularization is important because it turns processes into value creating activities.

Modularization is important in value rational engineering because it produces process values.

(3) Resilience

Zweckrational or theoretically rational engineering shows us a clear-cut path to the goal. But in Wertrational or value rational engineering, we need to go forward by trials and errors. Thus, learning from failures becomes very important in value-oriented engineering. To express it another way, the transition from theoretically rational engineering to value-oriented engineering implies we need to be more pragmatic in our engineering.

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