What is Systems Innovation (Part I)

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1. GAFA

On the first screen of the SIC home page, there is a small word "GAFA". This is a collective noun for Google, Apple, Facebook, and Amazon. I would like to begin this chapter by explaining the intention of using this buzzword at the top of the homepage.

Five companies (four GAFA companies and Microsoft) have been monopolizing the first to fifth place in the market capitalization of companies around the world for several years. This in itself is not so surprising. The top oligopoly may continue in any ranking. What is surprising is the market capitalization. Each company has a market capitalization of about $ 1 trillion. Speaking of $ 1 trillion, it is far beyond Japan's normal annual budget. It is not reasonable to simply compare the market capitalization as stock and the national budget as flow. However, confidence from the global market for the five companies is enormous. By the way, the market capitalization of Toyota, which is by far the top in Japan, is about a quarter of that.

GAFA's business continues to make significant changes in our lives. The Internet has become an integral part of our lives thanks to Google search engines. Amazon has made it much easier to get books and has changed the meaning of reading in our lives. Facebook has created new forms and a wider range of human connections. Apple has changed the way people live with smartphones. The great impact that GAFA has had on our lives has led the market to gain confidence in GAFA.

GAFA are all start-up companies that have been around for 30 years. The success of the business is highlighted by several dramas. Many books introduce the story. On the other hand, not many people are interested in the technical capabilities of GAFA that supported the success of the business. I think their technical capabilities are characterized by outstanding systemization capabilities: system thinking, system construction, and system operation. A superior system built with superior systematization capabilities support GAFA's business operations and brought great success. GAFA is constantly innovating the system. These are the reasons why I talked about GAFA at the beginning of the SIC website.

GAFA recruits a large number of doctoral graduates from top Western universities in the US and Europe, and welcomes researchers from universities with outstanding academic achievements as R & D personnel. Take the machine learning field as an example to see the level of GAFA R & D. In this area, there are several prestigious international conferences where the presentations are directly linked to the evaluation of researchers. One such international conference is ICML (International Conference on Machine Learning). The number of papers submitted to ICML in 2018 was 2473, and 621 papers were accepted as a result of the review (permitted to be presented orally or in the form of poster at the conference). The acceptance rate is 25.1%. It can be said that the adoption rate is extremely strict for an international conference.

Looking at the rankings of universities and companies with a large number of presented papers there, Google is far ahead of the 2nd and below. In addition to being the top, Google groups such as Google AI, Google Research, and Deep Mind (Alphabet) together account for 13% of the total published papers. Microsoft is 7th, Facebook is 9th, and Amazon is 22nd. Another international conference is NIPS (Neural Information Processing Systems), where Google is also at the top, and other GAFA companies are doing well with top universities such as MIT and CMU. What are these top-level researchers doing, using their capabilities?

Needless to say, the core of Google's business is search engines. Search engines are indispensable for databases and have been around since the 1970s. However, Internet search is a different dimension from previous systems. Tens of thousands of webpages are born and disappear every day in the world. Their content is also updated from time to time. Robots called crawlers run around world webpages to collect the latest information from such webpages. The number of webpages is said to be well over 1 billion, and the Google crawler visits those pages on average 30 times a day. The scale is beyond imagination. The information collected by the crawler is aggregated and organized so that it can be easily retrieved and stored in a large collection of servers called indexers. Necessary information is extracted in response to a request from the user, and output according to the importance level.

Search engines are evaluated by the speed of response and the accuracy of information. No one will use a search engine that takes time to come out or contains a lot of information you don't want. There were some web search engines before Google appeared. After a tough competition, Google now has a 95% share. The reason why Google has grown so much is that it has an excellent systemization ability to properly operate and evolve a huge search engine as a system in a rapidly changing web environment.

One of the factors that determine the quality of search engines is “ranking”, which measures the importance of webpages according to user requests. Larry Page, one of the founders of Google, proposed a ranking method called “page rank” as a way to evaluate the importance of webpages from the structure of the Internet connection (link) when he was a graduate student at Stanford. The results were made publicly available. At that time, many site administrators were anxious about the rise and fall of their site page rank. This technology was the start of SEO (Search Engine Optimization). The page rank method has some deep mathematical content based on graph theory and probability theory, and many related research papers have been published, after Larry Page proposed page rank. Currently, several evaluation methods superior to page rank have been proposed, and page rank is no longer used. It's important to know that search technology has this academic foundation and Google was a pioneer.

Amazon's starting point is the mail-order of books. In the beginning, it took at least two to three days for the book to arrive after ordering. Eventually, next day delivery was introduced, making it the best service among mail-order peers. The company quickly expanded its business and began selling books, clothing, everyday items, furniture, music, and video. Even if the total amount is large, it is not so difficult to extract, pack, and ship inventory if you only deal with books. However, the difficulty doubles when it comes to various products. Amazon's distribution center (full-fill center) uses robots for sorting and delivery, but robots don't go to the shelves. Instead, the shelf itself becomes a robot and moves to the sorting area. Unfortunately, I haven't seen the site yet, but that is probably the result of optimizing the overall system for efficient product purchase and placement.

Recently, Amazon Fresh, a business that delivers fresh produce within an hour of ordering, has started in the United States. Since it is difficult to handle fresh produce at distribution centers, a real store was born. It seems that hundreds of stores are already in operation in the United States.
A platform called “Marketplace” was created, which became a big boom. I also bought many used books from there. AWS launched by Amazon has grown rapidly and is now the world's best cloud business. Amazon has very high sales but extremely low profits. It is rumored that they have not paid corporate taxes or invested most of their profits in research and development. I don't know if it is true, but there is no doubt that the greatest effort is being put into system development.

I don't have much to talk about Facebook. The number of users is said to be 1.5 billion in the world, but I am not one of them. However, I think that the reason why FB became the champion among many SNS is that the system is excellent.

Apple's system innovation is embodied in smartphones (iPhone). The smartphone is the most advanced and most typical system product. We see that systemization of products is a dominant trend of modern technology. The integration of multiple functions is product systemization. For example, in the case of a “system kitchen”, water, gas, a cupboard, a kitchen table, a range, a refrigerator, and the like are arranged together so that cooking can be performed with short flow lines. There is no end to the systematization of industrial products: air conditioners with integrated heaters and coolers; cogeneration with integrated power generators and heat generators; combined machines with integrated printers, copiers, and fax machines; a hybrid car with a gasoline engine and an integrated battery engine. The best of them is a smartphone.

Before smartphones, mobile phones with various functions and portable computers called PDAs (Personal Digital Assistants) existed. However, today's smartphones have various functions such as telephones, computers, cameras, projectors, maps, and flashlights in a small casing. As a single unit, it can be said that systematization is pursued to the limit. Recently, some of them are equipped with various body sensors for health monitoring, and advanced musical instrument performance is also possible. Apple's great achievements led to the development of a mobile phone with an OS that integrates and operates various functions.

The essence of GAFA's work is to build, operate and evolve the system. GAFA has embodied its corporate philosophy, expanded its profits, and created system innovations one after another to challenge new businesses. Outstanding researchers working at GAFA continue to research and develop for larger, more complex, more sophisticated and smart systems.

２． History of system innovation

In the previous section, I mentioned GAFA as a modern example of system innovation, but system innovation did not start with GAFA, nor is GAFA a representative example. There are many system innovations in the history of technology. Especially from the latter half of the 19th century to the beginning of the 20th century, system innovations occurred one after another in infrastructure development such as transportation, communication, and energy generation. One of the most outstanding is the construction of a power transmission and distribution network by Thomas Edison.

At the end of the 19th century, gas lamps and arc lamps were used for lighting. As an alternative, many companies and inventors have rushed to develop incandescent bulbs. And Thomas Edison's invention won the development race. Edison was not only inventing the incandescent lamp, but also researching a power transmission and distribution system that would allow people to freely use it in their daily lives: building a system that integrates power generation, transmission, and distribution. This was a step ahead of other inventors who were thinking about batteries as the power source for incandescent lamps. Edison tried to fulfill the dream-like wishes of people at that time when they could plug in and use any amount of power at any time.

After winning the invention competition for incandescent lamps, Edison began building an actual power transmission and distribution system. He built a power plant in New York City and supplied power to nearby offices. Edison's vision had many twists to make it practical and had to overcome various technical difficulties. In the MIT Electrical Engineering Department in the 1930s, half of the professors are said to have been studying the stabilization of power transmission and distribution systems. Vannevar Bush, who later led the Manhattan project as the top military researcher in the United States, invented a "differential analyzer" for power network analysis at MIT. The fact that this later became the prototype of analog computers is a manifestation of the great ripple effect of system innovation through the power system.

Edison's belief that companies aim to make people's dreams come true also shares the corporate philosophy advocated by GAFA. Replacing Edison's "electricity" with Google's "knowledge" or Amazon's "product" reveals the commonality between the two. The goal for both is to make it easy for anyone to get what they want. The construction of the system is directly linked to people's needs.

The second example of systems innovation is the conveyer production line of the automobile created by Henry Ford. Prior to Ford, belt conveyors were used in production. For example, the conveyor system has already become widespread in the manufacture of sewing machines. It was also used for pig dismantling work, and Ford is said to have got a hint from it. However, at the time, it was thought that the conveyor system could not be used for products that are heavy like automobiles and require many parts and various processes to make. Contrary to its common sense, Ford gradually introduced the conveyor system into production line of T-type and succeeded in converting the entire manufacturing process to a conveyor system over almost six years.

The conveyor system required many improvements in parts and assembly methods that were different from before. New technologies were needed to deliver and transport parts between complex processes. It was necessary to perform optimal scheduling so that a bottleneck does not occur in the process. With the exceptional “systematic power” of Ford and his team, the conveyor production system was completed as a system overcoming these difficulties. In 1913, when the Ford T-type production system became a conveyor system at Ford's Highland Factory, a reporter from the Detroit Journal visited the factory and described its operation as "System, System, System".

In the military field, systemization is important as well as infrastructure. Radar was first put to practical use in the UK to quickly detect distant enemies that could not be seen with the naked eye. In the early days of World War II, the United Kingdom deployed a radar site network on the mainland and built an air defense system that linked air force bases to make enough time to wait for the incoming German aircraft. It is said that the radar air defense system was the main reason why British Air Force which was overwhelmingly inferior in terms of aircraft numbers, was able to defeat Germany over the months of the sky battle called the Battle of Britain. With the British victory, Hitler had to give up its invasion of the mainland. System innovation saved the country.

The air defense system was a completely innovative system at that time, making full use of the capabilities of the elemental technology of radar. Its success was exactly innovation. The system was developed to a larger scale in the United States during the post-war Cold War period. It was a supreme order for the US government to always be prepared for the arrival of Soviet bombers equipped with nuclear weapons. SAGE (Semi-Automatic Ground Environment) was created for that purpose. A computer-based communication system that began operation in 1958 connected radar sites across the United States. It calculated the speed, intrusion direction, and possible targets from radar images of enemy aircraft, and ordered the government and the US military to take appropriate actions. This huge system used 60,000 vacuum tubes, 175,000 diodes, and 12,000 transistors that were just put into practical use. Hundreds of tubes were replaced every day to run the system. It was a huge system that lasted 27 years, but it had never played an important role. In other words, the peace was kept.

It costed $12 billion for system development of SAGE which exceeded the total cost of the Manhattan Project that developed the atomic bomb. SAGE is not only a pioneer in computer communications, but also the first practical use of online and distributed processing, and has left its name in the history of computer technology. IBM, who was in charge of the development of SAGE, took advantage of the technical capabilities cultivated in SAGE and won the computer industry thereafter. It shows again the magnitude of the ripple effect of system innovation. Many other system innovations originate from military purposes. The Internet and GPS are the best ezamples. Needless to say, both have been making a great impact on our lives.

Japan also has excellent results in system innovation. Here, I would like to mention the Shinkansen operation management system in the early 1960s and the integrated steelworks production management system.

The Tokaido Shinkansen, which started in 1964, was capable of running at 200 km / h, and several trains ran in one hour during the most frequent times. An excellent operation management system for safely operating trains required a highly accurate and complex system that connected the ground instruction system to the train. At that time, Japan National Railway(JNR) built a system for that purpose and successfully operated and evolved the system without causing major accidents. Currently, the maximum operating speed of the Shinkansen is 320 km / h, and 13 trains run in an hour during busy hours.

An operation management system is also used for ticket reservations. JNR has been developing an automatic reservation system called MARS (Magnetic Electronical Automatic Seat Reservation System) since the late 1950s in order to meet the rapid increase in passengers. MARS, which began operation in 1960, is the world's first railway reservation system. Before that, ticketing was handled by the operator over the phone, so it took at least 2 minutes and sometimes more than 30 minutes to get an express train ticket at the station window. MARS shortened it to about 30 seconds. It was a great innovation. The Shinkansen was able to start operating smoothly thanks to MARS.

The Japanese steel industry built several integrated steelworks with an annual output of 10 million tons from the 1960s to the beginning of the 1970s. The steel making process is extremely complex. It deals with all forms of substances: solids, liquids, gases, granules, and powders. Also, a continuous process based on chemical reaction and a processing process based on physical deformation are mixed. The process temperature also ranges widely from minus 200 degrees to 2000 degrees. Moreover, steel making is custom-made. Each order must be tracked at all times. For this reason, production management is very complicated and difficult. Even at the US Steel factory, which had the largest production volume at that time, production management using a large number of people had reached the limit of 5 million tons per year. To break through this limit, the Japanese steel industry has achieved system innovation in production management.

When Shinkansen operation management and steel production management were introduced, computer technology was poor in Japan at the time. It is remarkable that a large-scale system has been introduced and operated successfully. It is true that the introduction of computers ultimately became a decisive factor for system construction. Nevertheless, they were able to build a system that greatly exceeded the world level, because they had a deep understanding of the system's purpose, structure and operation, and a clear vision of the system they wanted to create. At the Research Institute of JNR, the Norbert Wiener's book "Cybernetics", one of the sourcebooks on systems science and technology, was widely circulated long before its Japanese translation came out. Cybernetics was translated into Japanese and gained attention after the Shinkansen began. This means that JNR Research Institute had a technical philosophy that valued system technology a long before computer technology matured in Japan. History encourages reflection on the current state of Japanese industrial technology and management, which is dominated by the idea that IT is everything.