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TRIZ Methods Applied to the Analysis of Disruption in the Marketplace

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Abstract

Since its conception by Everett Rogers (1962), the "S-curve" has been known and used for more than 50 years. The S-curve model has allowed for the prediction of market disruption but has consistently failed to predict the timing in which when disruption would occur. Adner and Kapoor (2016) provided a framework that links the evolution of an incumbent challenged by a new technology to the evolution of the ecosystem, which they claim provides a predictive model for the occurrence of disruption. According to the authors, the "mode" and timing of a disruption may now reasonably be predicted. From a practitioner's point of view, the question at hand is how to identify the right strategies and the subsequent tactics to respond to each of these disruption scenarios, for both the position of the incumbent and the new entrant. We propose these answers can be found within the body of knowledge offered by TRIZ. The utilization of these practices can guide incumbents and contenders to specific strategies that can be employed when engaging with each scenario of disruption. Policy-setting and regulation can also benefit from such analysis. We demonstrate the approach with a practical case study from the construction industry.

Keywords: Disruption, S-Curve, Technology Trends

1. Introduction

In the discussion of innovation and disruption, the "S-curve" is a well-known concept to describe the maturing of systems. Altshuller (1984) distinguishes between the four stages of "childhood", "growing up", "maturity" and "old days", which others have further expanded, for example by D. Mann (1999).

Better known among marketers is Everett Rogers' (1962) earlier use of the S-curve to describe the diffusion process of innovation. Rather than maturity or performance of the system, the degree of adoption is tracked, which is the mathematical integral of the rate of adoption (see Fig. 1). In this view, the S-curve is understood as a special case of a learning curve. Notice that also other learning curves are observed, for example hyperbolic ones (Thurstone, 1919), where learning is fast initially and then becoming more incremental.

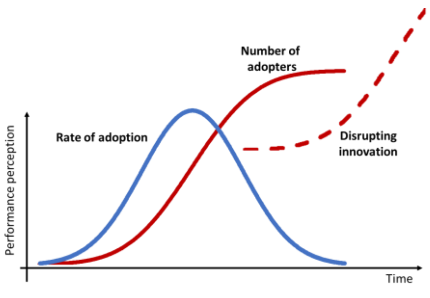

Fig. 1: R. Everett's model (1962) for the diffusion of innovation

One of the first things an innovation practitioner will want to determine is a system's position on the S-curve – be that with regards to maturity, performance, or stage of diffusion. Based on Altshuller's original work, evaluating the evolution over time of four metrics can be used to accomplish these assessments, including: the system's performance, the number of related inventions, the level of these inventions and profitability of each, as discussed in more detail by M. Slocum (1999). One can include Roger's view in such a study and add degree and rate of adoption (Fig 2). TRIZ practitioners would then validate the resulting findings through a technology trend analysis, either based on Altshuller's original 8 trends (1984), or on more granular formulations, as proposed by D. Mann (2002). Such analysis not only validates the system's position on the S-curve, it also further helps identify the evolutionary potential within the current system and predict developmental paths to increase the system's maturity.

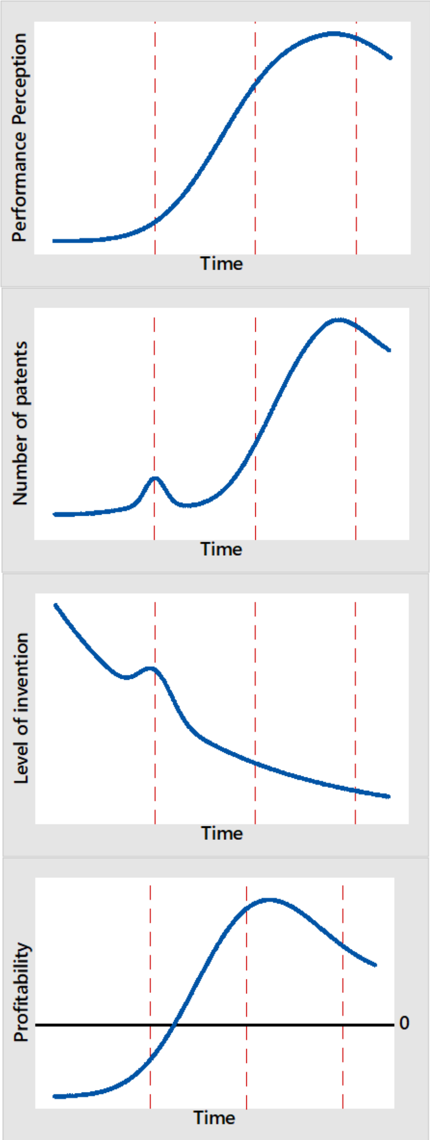

Fig. 2: Stages of technology evolution (adapted from Slocum, 1999). These four metrics along with Roger's two metrics from can be used to determine the position on the S-curve of a given system.

Adner and Kapoor (2016) provided a framework that links the evolution of an incumbent, challenged by a new technology, to the evolution of the ecosystem, which they claim provides a better predictive model for the occurrence of disruption. According to the authors, "mode" and timing of disruption may now be reasonably predicted.

From a practitioner's point of view, the question at hand is how to identify the right strategies and subsequent tactics to respond to each of these disruption scenarios, for both the position of the incumbent and for the new entrant. Based on our investigation, in this early phase still with a limited set of data, we propose searching the answers within the TRIZ body of knowledge, such as the analysis of trends, inventive and separation principles, and others. The utilization of these practices can then guide both the incumbent and the contender to specific strategies they can employ when engaging with each of the four scenarios of disruption described by Adner and Kapoor.

2. Analysis of disruption scenarios

When engaging in a maturity and diffusion analysis, disruption is observed as a possibility, when a new technology, initially inferior, over time supersedes a mature incumbent system. This phenomenon of disruption has been studied by G. Schmidt & C. Druehl (2008), C. Christensen, C. Raynor and M. McDonald (2015), G. Pisano (2015) and others.

Using concepts such as the "Sun Diagram" proposed by D. Cavallucci (2007), practitioners can also predict where disruption is likely to happen. In the practice of this tool, different technologies are compared using a function and contradiction analysis, and roadblocks are identified that hinder the technology from evolving towards the "ideal final result". Such an analysis helps predict which of the emerging technologies are most likely to challenge an incumbent.

Upon identifying how the incumbent will be challenged by competing systems, the strategic feat is the prediction of when disruption is likely to occur. R. Adner and R. Kapoor (2016) claim to have developed a model to address this problem. The authors link the evolution of an incumbent system, which is challenged by a new technology, to the evolution of the surrounding ecosystems. From a given starting position, shown as "Today" in Fig. 3, they identify four possible scenarios in which to perform this evaluation (also see Table 1). We will discuss selected known scenarios.

Mode A - The LED disrupts the incandescent and halogen lights

A well-known example for classical disruption is the replacement of the incandescent and fluorescent lightbulbs by LEDs. LEDs were present since the 1960's, yet they were constrained by their low power capabilities, producing light predominantly in the red frequencies of the spectrum. Development continued throughout the mid-1990's, at which point blue and brighter LEDs were created and introduced to the market, but the desire for a white LED light remained. In 2007, efforts were spurred on to achieve this through a competition set forth by the US-American Department of Energy, the "Bright Tomorrow Lighting Prize" (https://www.lightingprize.org/). And alas, in 2011, with four years of effort, this feat was achieved by Philips. Today, the incandescent and fluorescent light bulbs are replaced almost entirely with the white LED light. This was possible 1) thanks to its enhanced performance as a LED of 10 Watts that provides about the luminosity of a 60 Watts incandescent bulb and 2) thanks to its compatibility with the existing ecosystem as the new LED bulbs fit into the classical "Edison screw" socket. Both has resulted in a quick, easy substitution.

Table 1 Four disruption scenarios when considering the ecosystems of incumbent and new technology (adapted from Adner and Kapoor, 2016).

		New Entrant Ecosystem	
		Must be improved	**Is ready**
Incumbent Ecosystem	**Can be improved**	**Mode C:** Robust resilience of the old technology	**Mode B:** Robust coexistence between old and new technology
	Has reached maturity	**Mode D:** Illusion of resilience of the old technology	**Mode A** "Classical" creative disruption of the old by the new technology

Mode D - Paper maps become virtually extinct by GPS Navigators

Paper maps, in various forms, have prevailed as the go to method of navigation in unfamiliar territory. However, navigation using a map while driving is unsafe and error prone. As roads and infrastructure is updated, paper maps also become quickly out of date. Global positioning system (GPS)-based maps, in both dedicated GPS navigation units as well as smartphones. These applications mitigate the concerns around paper-maps by offering up to date maps, that also highlight immediate traffic conditions, road hazards, speed-control points and other information that is of interest to a driver. GPS-based navigation demonstrated an early win for the technology, but its widespread adoption was hampered by the lack of a supporting infrastructure or ecosystem. A functioning GPS navigation system depends on satellite-based positioning information, affordable GPS-capable devices, such as smartphones, affordable and fast data-services, as they are now provided by mobile network operators, interactive mapping software as well as easy-to-use interface, allowed for today with the ubiquitous touchscreen devices. Initial forays into the consumer GPS navigation market by providers such as Garmin, were viewed as a niche application from the perspective of map publishers. Only when reliable mobile network connectivity became available and affordable, coupled with freely available map information, such as was published by companies like Google & Apple, were traditional map publishers replaced in the market. The incumbent paper-based navigation maps were not initially threatened by GPS based market entrant solutions, because the latter initially found limited application. However, as the eco-system evolved, supporting technology developed and GPS navigation ultimately improved to outperform paper-based maps from the perspectives of convenience, accessibility, speed, accuracy and flexibility

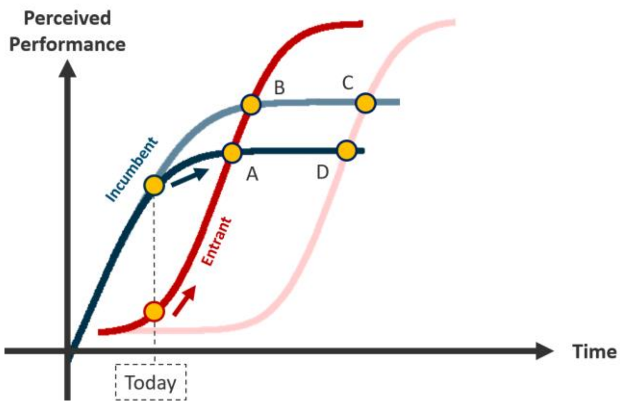

Fig. 3: Paths of disruption for four different scenarios, depending on the evolutionary potential in the incumbent's and the new technology's ecosystems (adapted from Adner and Kapoor, 2016).

Mode B- The snowboard fails to disrupt the ski

The ski appears to have been invented multiple times in different areas, and likely for the first time about 10,000 years ago in what is today's China (New York Times, 2017). Since creation, the design of the ski has continued to evolve, namely with the advent of new materials. Efforts to improve the design of the ski dwindled down through the 1980's.

As early as 1939, a patent was granted for a sled as "substitute for skis in jumping on snow or snow-covered ground" (US2181391A). In the mid-1960's, the first truly snowboard-like design emerged under the name of "snurfer" (US3378274A), which stands for "snow-surfer". Only in the late 1970s and early 1980s, after the release of the 1985 James Bond film, "A View to A Kill" did the idea of snow-surfing gain popularity in concept and experimentation. Snowboarding was distinguished for bringing the attractive elements of surfing on Californian beaches to the snow-covered mountains in America, Europe and elsewhere. The ease of learning this sport greatly increased its desirability, as demonstrated by daring snowboarders who were able to perform on terrain considered "impossible" by means of skiing.

With an attractiveness to extreme users and accessibility for the larger public, one could have expected the snowboard to take over an important share of the market for skis. What was unforeseen, was the span of development still available for the ski design to advance upon. Thus, after thousands of years of development and perfection, the ski evolved to include a carving feature, a design element borrowed from the curved shape of the snowboard. The new design featured a shorter ski length, which provided a social benefit and thus greater adoption for non-expert skiers, previously mocked for use of non-traditional short skis. The addition of the curved feature allowed greater comfort and a smoother ride, increasing its performance across moderate to tough territory. These enhancements made the experience of the sport more widely attractive, inviting even the un-experienced, occasional skier.

The ski exemplified the scenario of robust resilience, in which the ski evolved to compete against the snowboard, protect its market space, and gain more amidst the introduction of the snowboard. One can now expect the ski and the snowboard to co-exist at least for some time to come while incremental improvements occur, and debates persist over beneficial features such as easy step-in, advancement on flat sections of slopes, likelihood and nature of typical injuries, ease of use under spring-snow conditions and so forth.

Mode C - Is the combustion engine resilient enough – or will the battery or hydrogen prevail?

A more complex situation is the ongoing debate around the internal combustion engine versus the battery- or fuel-cell-driven electric motor versus the hydrogen combustion engine. In the public debate, battery-driven electric vehicles are often presented as the obvious future of the industry. Yet, that view requires scrutiny: First, incumbent car manufacturers still see significant evolutionary potential in the "classical" combustion engine, through advances in fuel-efficiency and the reduction of harmful effects produced by NOx, CO_2, CO, and unburned hydrocarbons. The incumbent technology is also positioned with advantage as the existing ecosystem predominately caters to this solution with a vast presence of dealerships, gas stations and repair shops.

Further, when thinking "backwards from perfection", i.e., using the "ideal final result", as the TRIZ practitioner would do, one also examines the ideality of the energy-storage solution and compares the energy-density for gasoline, battery, and hydrogen, and this in terms of weight (Joule/kg) and volume (Joule/m^3). Hydrogen (whether used in the fuel cell or in a hydrogen combustion engine), outperforms any known battery concept and beats gasoline in terms of energy stored per weight, although not per volume (e.g. Wikipedia, https://en.wikipedia.org/wiki/Energy_density). Furthermore, the use of rare earth and other materials in electric motors, and the materials required for current designs of high-performance batteries, add considerable "harm" to the end-to-end lifecycles of electric motors. As a result, the automotive industry, incumbents and new entrants, explore all four options: the improved "classical" combustion engine, a hydrogen combustion engine and the battery and fuel-cell powered electric car. Predicting the evolution of the combustion engines alongside the rate of adoption for the other technologies is a scenario where TRIZ thinking and TRIZ practices provide guidance not only for inventors and strategists but also for regulation and policy-setting.

3. A strategist's TRIZ-based disruption analysis

TRIZ practitioners notice that Adner and Kapoor's re-formulation of the S-curve incorporates Altshuller's original analysis into aspects of the nine-screens method. Their methodology conceptually analyzes the technology in the past, present and future, for system and ecosystem (the super-system from a TRIZ perspective), but not for the sub-system. TRIZ practitioners may thus concede that Adner and Kapoor's model is not fundamentally new to the TRIZ community, and even incomplete. Yet, in our practical work with client teams, we find their four disruption and resilience scenarios highly useful, and this both for contenders and for incumbents in their respective situations. We also acknowledge that the framework provided by Adner and Kapoor allows for encompassing analysis and provides valuable insights.

As can be seen namely with the complex "mode C" example above, strategists can indeed further expand the concepts developed by Adner's and Kapoor when complementing them with TRIZ methods and understand what strategies incumbent and contenders may develop in the face of disruption. The general usefulness of TRIZ thinking for strategists has been explored in another of our articles (M. Ohler, P. Samuel, N. Shahani and D. Bennington, 2016). Here we see how TRIZ methods, combined with the observation of patent and research activities, help each party anticipate the others' next likely moves and plan their own strategy accordingly. TRIZ capabilities in an organization then turn into a tangible, strategic advantage.

The iPad may serve as an instructive example, as it is sufficiently well-documented in the public domain. Almost four decades ago, Steve Jobs (1983) formulated his vision:

"What we want to do is to put an incredibly great computer in a book that you can carry around with you and learn how to use in 20 minutes ... and we really want to do it with a radio link in it, so you don't have to

hook up to anything and you're in communication with all of these larger databases and other computers."

The system Jobs described, an amalgam of a computer and a book, did not only require the readiness of ecosystems such as the internet (the "larger databases and other computers") but also the readiness of sub-systems such as "radio links" (read: W-LAN) with high data transmission rates, small and low-power processor- and memory-units, a high energy-density battery and not least, suitable display technology to fit on the "book". It is known that strategist Steve Jobs actively monitored the evolution of relevant super- and sub-systems, as well as the successes and failures of pre-cursor products such as the Samsung's GRiDPad, Fujitsu's PoqetPad, Apple's own Newton and the Palm – which increased his chances to avoid the trap of "right product – wrong time"; the very title of Adner and Kapoor's article.

The study of disruption scenarios helps the practitioner learn from both the perspective of the evolving system and eco-system, as well as the sub-systems. With that understanding, the next logical step is to not only include Altshuller's first, but rather all 8 trends in the analysis.

Another conclusion made by the TRIZ practitioner is to expand the study of disruption by employing a full ARIZ analysis (G. Altshuller, 1985). If that were done and skillfully so, then the "short-cut" method for analyzing scenarios of disruption, as discussed here, might not even be required. From our field-experience with clients we also learned that such an approach limits the study of disruption timing to the small number of highly experienced TRIZ practitioners, and to teams willing and capable to adopt the ARIZ framework. The question thus is: How can strategists, with an interest in the application of systematic methods, make their current practice more insightful by encompassing the application of TRIZ approaches? With a strategist's long to-do list, we see a simplified approach, such as shown in Fig. 4, as what can, and should, be integrated in such a strategic analysis. If, say, the betting of large sums of investor money on a hydrogen combustion engine were at stake, that turns into a key element of the "due diligence" investigation.

With an interest in experimentation, and with the constraint of often short time for the training of client teams, we have condensed the full ARIZ process into the subset of techniques shown in Figure 4. This figure represents the flow of analysis that we utilize in a standardized approach to the study of disruption situations.

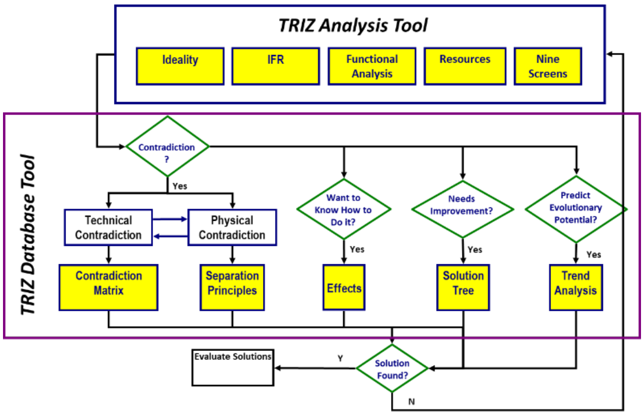

Fig. 4: A simplified approach for using TRIZ methods to derive strategic options from a disruption analysis.

This work is found to flow well when conducted during client workshops as described by M. Ohler, N. Shahani and S. Borde (2015). Once a team identifies entrant and incumbent systems, we supplement the common strategy analysis (Porter's Five Forces, SWOT, Capabilities, …) with this framework. In this phase of a strategy workshop, the teams review incumbent and entrant systems, their resources, and functions. A similar analysis is performed for the eco-systems with the help of the nine screens approach. We then continue to isolate useful and adequate functions, useful but insufficient functions and harmful functions of the incumbent and entrant systems, and this from the perspectives of product life-cycle and customer-journey. Then we formulate the Ideal Final Result and Ideality of the systems. Analysis of the position and distance of incumbents and entrants with reference to Ideal Final Result then helps formulating the contradictions that must be solved by the players for their respective technologies.

Armed with information thus gained, the teams then create strategic options for incumbents and entrants by applying inventive principles, separation principles, scientific effects, substance-field, and standard solutions. The resulting options then inform robust approaches towards handling a given scenario of disruption-mode and disruption-timing.

4. Case Study

With the following case study, we intend to illustrate how the approaches discussed here can be applied in practical terms.

A new structural framing system tool, known as Framefast®, has been recently introduced in the marketplace for attaching rafters and trusses with a single 6" fastener (see https://www.fastenmaster.com/products/framefast-system.html). This new entrant is trying to disrupt the incumbent system composed of various types of metal plates (such as a hurricane joint), fasteners, pneumatic nail guns, hoses, ladders, and scaffolding.

An essential step in providing structural integrity for buildings with wood framing against conditions such as wind, snow and storm include attaching of various rafters and trusses. The current method of attaching involves use of multiple metal joints with fasteners. For example, an H1 hurricane tie from Simpson Strong-Tie provides a positive connection between truss/rafter and the wall of the structure to resist wind and seismic forces (see https://www.strongtie.com/resources/product-installers-guide/h1-installation). Fig. 5 provides examples of trusses or rafters connected with such joints created with metal plates and fasteners.

From an S-curve perspective, the incumbent system is a mature system. The eco-system includes pneumatic nail guns, hoses, ladders, scaffolding and human operator. The system and the ecosystem have evolved over the last decade and have reached a plateau in terms of its capabilities and functions. Typically, a human operator must climb the ladder, attach a variety of plates manually and then install the fasteners. It is sufficing to say that the incumbent method is cumbersome, labor intensive and unsafe. This provides the context for the innovation of the new entrant system called, Framefast®.

The new entrant system boasts eliminating the disadvantages of the incumbent system while providing additional advantages such as the elimination of the incumbent eco system composed of ladders, scaffolding, nail guns and hoses. It also eliminates all forms of metal plates used to join the structural members. This is achieved with the help of a newly designed tool, called Framefast® as shown in Fig. 6. The system allows for the elimination of the ladder and scaffolding as the installation is done on the deck level with the help of extendable tool. The tool holds a special fastener which can be directed and applied to join the structural elements without any special metal plates. It is claimed that the installation is done up to 8 times faster than the traditional method. The tool comes complete with a high torque drill and patented delivery system. The alignment wings can be folded back for girder trusses or harder to reach application. For vaulted ceilings or rafters, the backstabber feature can be raised to meet the bottom of the truss or rafter.

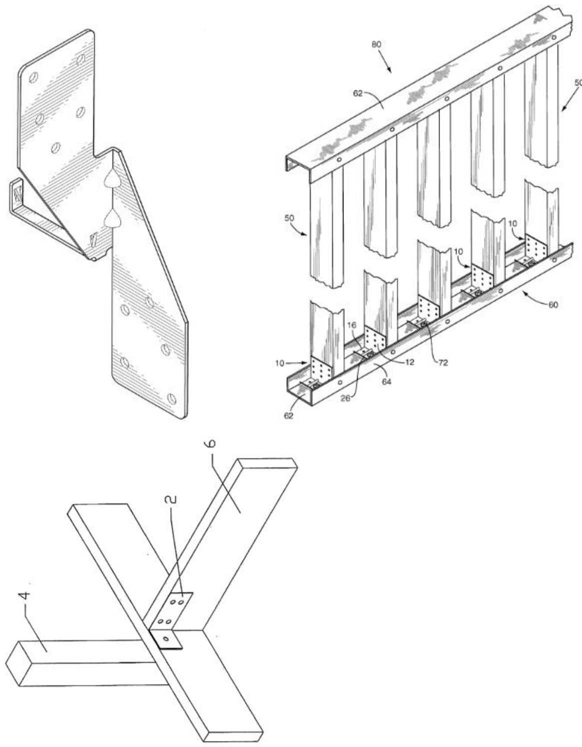

Fig. 5: Examples of incumbent systems to attach rafters and trusses [USD768470S1, US5467570, US20080115447A1].

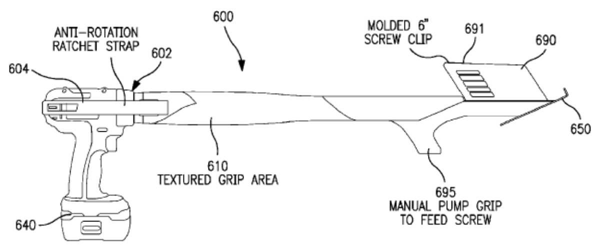

Fig. 6. Framefast® tool (new entrant) [US 20150101462].

We now evaluate the new system, using the framework provided by Adner and Kapoor, for its ability to disrupt the incumbent system. In this framework, there are four questions to be answered:
1) Is the new entrant ecosystem ready for wide acceptance by the stakeholders?
2) Must the new entrant ecosystem be improved before wide acceptance?
3) Has the incumbent ecosystem reached its maturity?
4) Can the incumbent ecosystem be improved against the attack from the new entrant?

Table 1 provides the framework to predict the mode of disruption based on the answers to these questions. The answers are then made robust by bringing additional analysis provided by TRIZ perspective.

From TRIZ perspective the insufficient functions of the incumbent systems include positioning and holding metal plates, such as hurricane tie in place, pre-drilling the location, and driving the fastener into the joints. The harmful functions for the incumbent system include safety hazards for humans while using the ladder, scaffolding and nail gun. The insufficient function of the fastener penetration is traditionally improved with the help of pneumatic nail gun with compressed air hose. However, this creates a technical contradiction resulting in additional harm, cost and inconvenience. Another technical contradiction is that the use of scaffolding and ladder improves the ability to position and attach the metal plates, but it lowers productivity and increases safety risk.

The ideal system to join trusses and membrane would have very limited resources in it, with perfect joining capabilities while providing no harm or cost. Such a system should eliminate most of the elements contained in the incumbent ecosystem. Therefore, it makes sense for the new entrant to find ways to eliminate harmful and cumbersome steps of using ladder, scaffolding, variety of metal plates for different types of joints and pneumatic accessories needed to drive the fastener, and the need of pre-drilling. From this perspective, we believe that the incumbent ecosystem has reached its maturity.

While the new entrant has eliminated the metal plates, at present, regulatory codes require its use in various locations of USA. Before it can be adopted, the new entrant must find ways to influence the code, although they have verified that the joints installed by the new system exceed the structural requirements. In addition, the new ecosystem still has many harmful functions and costs to be overcome. For example, there is a significant cost associated with the acquisition of the Framefast® tool. It requires storing, transportation, maintenance, and repair. While it has eliminated the ladder, scaffolding and pre-drilling, it still requires pneumatic or electric accessories to provide power to the drill. While the new system has considerably improved the productivity of installation, the system at present only allows one fastener to be loaded at a time for installation. As such the operator must load the tool with a new fastener each before installing it. Considering these facts, we conclude that the incumbent ecosystem must still be improved before it can be widely accepted. Hence, we believe that the mode of disruption is one of "illusion of resilience" (mode D) as Framefast® must improve its ecosystem on many of the dimensions described above before it is capable of disrupting the incumbent system.

5. Concluding Remarks

The model developed by Adner and Kapoor provides easily accessible explanatory and predictive power for timing and mode of disruption. The model gains its power from including in the analysis the ecosystem rather than considering only the innovation itself. We find useful to also include the evolution of sub-systems in such an analysis to better predict mode and timing of future disruption events.

The practitioner's concern in that is not only to anticipate future disruption but also how to best use the resulting insights and how to deal with a given competitive situation, and this both from the position of incumbents and new entrants. As we have seen with the automobile motor and source of energy, this can be a setup with multiple technologies, and in most cases, it will also include multiple agents both on the side of the incumbent and of the contender.

In situations as complex as these, we see the full TRIZ body of knowledge as highly relevant: Is the new solution currently held back by a contradiction at system, super-system, or subsystem level? Will scientific effects help improving insufficient or neutralize harmful functions along product life-cycle and customer journey? What evolutionary trends are most applicable to the situation? Given what a strategist sees on a trade fare, or finds published or patented by competitors, suppliers or customers: what road is incumbent A or contender B likely to follow?

In our work we see how thorough TRIZ work helps organizations break down such complex setups into manageable pieces of study that can then be used to develop specific strategic options.

We see this article as a first step that provides the practitioner with methods, a roadmap how to proceed, and with practical examples. From a scientific point of view, this article exposes our own informed hypothesis. As one possible next step, the proposed expansion with TRIZ-methods of the disruption model by Adner and Kapoor can be validated with a larger number of case studies, including our own still unpublished work, as they are already or become available in the public domain. We are convinced that the results of such scientific work, based on a large enough sample size, will also allow practitioners to sharpen their own methods, make these more approachable for teams with less TRIZ expertise, and allow for the definition of specific strategies how to deal with multi-technology-multi-agent disruption situations.

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The Application of Modern TRIZ in the Analysis of Patent Defense of Functional Pot with Vertical Cover

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Abstract

How to defend the patent application effectively is not only the responsibility of the patent agency, but also requires the cooperation and active recognition of its applicant and its inventor, for which there will be a greater chance of winning the defense. Since last August, the theories of the Strengthening and Regeneration of Systematic Patent Avoidance that belongs to modern TRIZ, written by Xu Dongliang, a professor from National Tsinghua University, TRIZ' s Golden Key to Innovation ,written by Sun Yongwei and other theoretical methods, were introduced to us, we attempt to apply functional analysis, functional attribute analysis, patent avoidance, patent reduction, and hierarchy view to the process of defense analysis. Therefore, it's believed that such methods play better guiding roles in the analysis of patent application defense and defense statement, improve the chance to win the defense, and help to get the patent grant, so it's worth a bold try.

Keywords: TRIZ Theory, Strengthening Patent Avoidance and Regeneration, Defense of Patent Application

1. The Notice of First Audit on Functional pot with Vertical Cover and its Molding Methods

The notice of first audit on Functional Pot with Vertical Cover and its Molding Methods (201610658173.1) was received in Nov. 2017, and the examiners listed total 6 comparative patents (Fig. 1, 2, etc.), believing that: "There is no substantial content awarded with patent right in the patent application; if the applicant does not state the reason or the stated reason is insufficient, the application shall be rejected".

According to Article 37 in the Patent Law of the People's Republic of China, audit opinions shall be replied in set time, and if the reply is overdue, the application shall be deemed to be withdrawn. The reply to audit opinions is inseparable from technical fields, problems, solutions and effects, so it's necessary to comprehensively find innovation in the claims, instructions and unambiguous contents in the figures attached to the instructions around audit opinions and argue. Even if technical problems are similar or identical to comparative files, they can still be innovative.

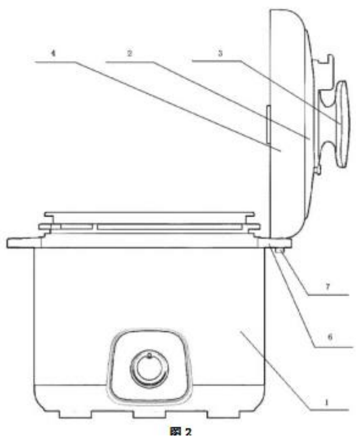


Fig. 1 Split-type Electric Pressure Pot

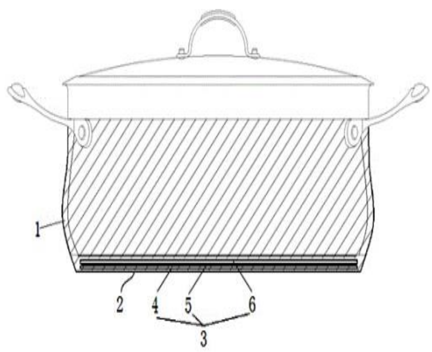


Fig. 2 Short-wave far infrared pot

2. Preliminary Analysis of Major Comparative Patents

Analysis needs to be made prior to patent defense. As for conventional practice, mind mapping can be used to compare and analyze technical fields, problems, solutions and effects one by one, as shown in Fig. 3. The content of application is listed on the four blocks in the figure, and major comparative patents (1) and (2) are respectively listed in the middle and lower part. Through preliminary analysis: its technical problems are not the same as technical solutions, and technical effects of this application are more and better (emission conducive, energy saving etc.) than those of comparative patents (1) and (2). This will have a certain impact on the check and description of subsequent sufficient reasons, so that the confidence in defense will be enhanced. However, it's also necessary to carry out further analysis, especially in terms of technical characteristics and effects in order to persuade the examiner.

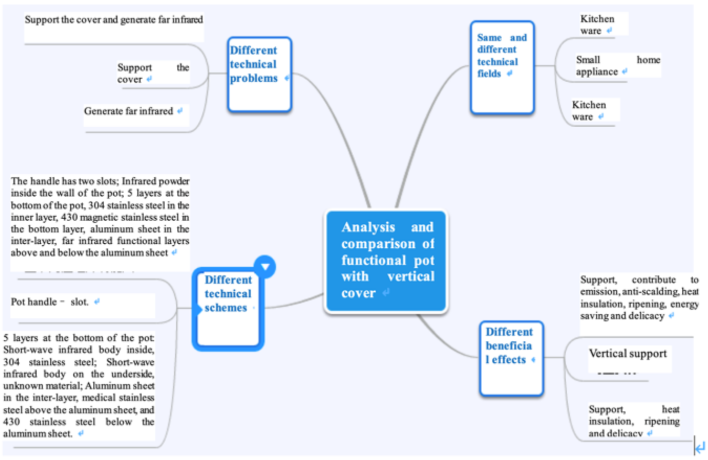


Fig. 3 Analysis and comparison of the application and comparative patents (1, 2)

3. Debate on the Vertical Cover

The examiners compares comparative patent (1) Split-Type Electric Pressure Pot[5] with the application, and proposes that: "Referring to Figs. 1-2, this pot equals to a functional pot with vertical cover, and the slot is installed on the handle for cover plug-ins and connectors". It's easy for technicians in the field to think out the slot on the cover handle as an alternative". "equal to" and "easy to think" here are fatal, indicating that this pot has nothing special, and this distinctive feature of the application is not creative or obvious.

Three distinctive technical features listed in the agent's defense are shown in triangle 1, 2, 3 of Fig. 4. First: "In comparative file 1, the pot cover needs to be provided with an additional connector to be connected with the connector groove on the pot body. The slot in this application is used to insert cover handle directly, which can effectively reduce members on the cover and the difficulty of cover molding. Therefore, these two are different in structure and function." We believe that the agent's defense only mentions "the reduction of pot cover members" and "the smaller modeling difficulty of pot cover", which is insufficient. In this way, the defense is not deep enough, so it will lead to the misunderstanding of examiners that it doesn't make much difference.

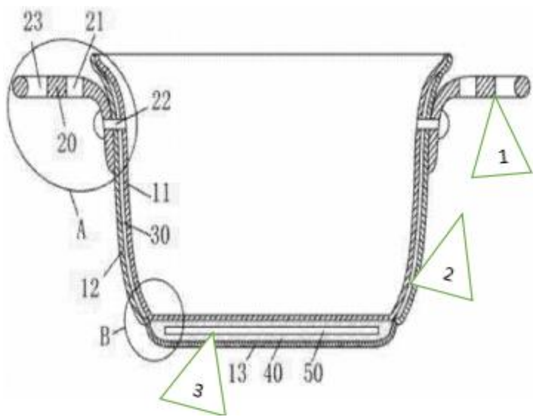


Fig. 4 Fig.1 of the present application

To this end, we have tried to use functional analysis and functional three element analysis (Fig. 5、6) described in Strengthening and Regeneration of Systematic Patent Avoidance, TRIZ' s the Golden Key to Innovation and other theoretical methods, believing that the main function here and receiver of the function, i.e. the cover handle or the cover connector, are basically the same; while "tools" are different from "function providers" i.e. there are still obvious differences between two "pots", so the pot is marked as "×" in the Fig. 7. However, the examiner thinks that the text expression of "pot body" in this application and the comparative patent (1) is the same, it is "pot body with slot on pot handle". If so, the problem of answering the examination will be serious.

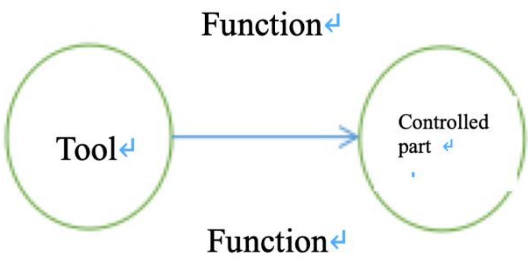


Fig. 5 Analysis of four functional elements

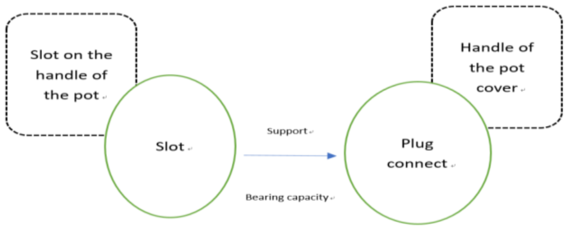


Fig. 6 Analysis of four functional elements in the application

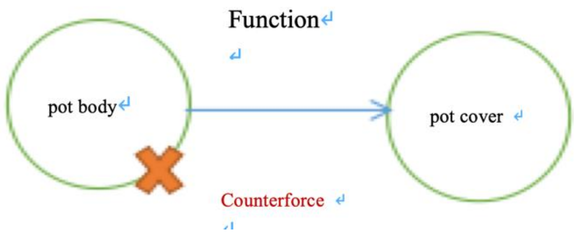


Fig. 7 Analysis of four functional elements in comparative patent 1

In order to deal with the serious situation in the trail, it is necessary to carefully compare the technical features between the two, so the comparison starts from Fig. 8 and Fig. 9 or Fig. 4: The pot body of the comparative patent (1) in Fig.8 is actually the outer shell of the electric pressure cooker, while the pot body of this application in Fig. 9 is close to the inner container of the electric pressure cooker, and its inner cavities are all used for containing food, indicating that this pot body (Fig. 9) is not the another one (Fig. 8). Although the meanings of " slot on the pot handle" and "plug slot on the pot handle" in the instructions are almost the same, it is different from the analysis of functions and components. From Fig. 9, it can be seen that the pot handle in the drawing of this application is also provided with2 slots (its original reference number is 21 and 23). Therefore, 2 useful functions are produced (as indicated by the arrow), of which the handle of the pot (original reference No. 20) can lift up or carry the pot, which is a known technology; as shown in Fig. 9 (No. 21), it can support the cover of the pot upright, which is different from the existing technology in Fig. 10; reference No. 23 stands obliquely to support the pot cover in Fig. 9, which helps to discharge oil-smoke and steam (the pot body is particularly suitable for being used as hotpot). As shown in Fig. 11, this is totally innovative technical feature and a function that can infer its technical effect. However, in the comparative patent (1) of Fig. 8, there is only one slot on the pot handle of the outer shell of the pot body, which has only one support function. That is, pressure pot cover is supported on the pressure pot shell.

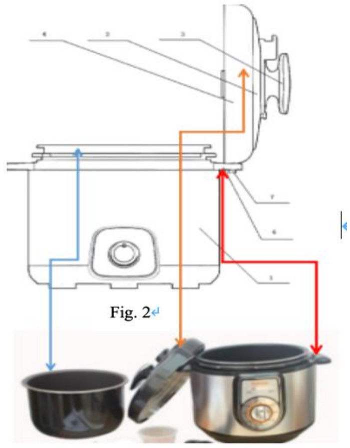


Fig. 8 Schematic and physical diagram of the electric pressure pot in the comparative patent 1

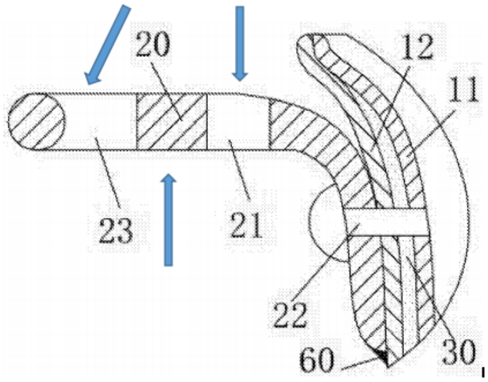


Fig. 9 Fig.1: Pot handle of this application

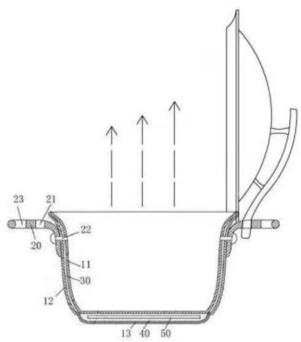


Fig. 10 Pot cover vertical support in the figure attached to the application

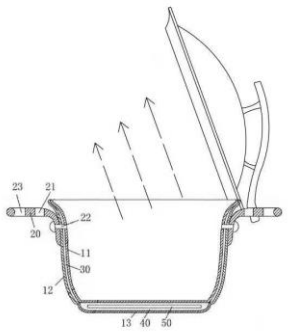


Fig. 11 Pot cover oblique support in the figure attached to the application

It's found through the above comparison and analysis that: Firstly, the agent and even the examiners misunderstood the words "tool" that produces the supporting function, namely "pot body", so that this pot is equivalent to the other one. Secondly, there is no in-depth comparison and analysis of the features and functions of the pot, pot handle and component tools, completely ignoring the difference in technical characteristics and beneficial effects. On the contrary, after functional four element analysis and the analysis of functions and components, it indicates that the handle of the pot in this application has another 2 slots (The technical problem to be solved is: how to better support the cover of the pot, which is not obviously shown). Its useful function is more powerful. That is, beneficial technical effect is more remarkable. As shown in Fig. 10, it can support the cover of the pot upright; as shown in Fig. 11, it can also support the cover of the pot obliquely, so that the oil-smoke and steam in the pot are discharged in side direction. These technical features are not found in all comparative patents, are non-obvious technologies and have prominent substantive features.

The above analysis shall be converted into the language for defense (for agent reference), that is: based on the distinctive technical feature (1), it needs an additional connector on the pot cover to connect with the connecting slots on the pot. (This "pot body" is different from that of the application, so people may misunderstand; the "pot" actually is the outer casing of the electric pressure pot, and the cooker contains water and food materials, which does not have "ear"). As for the pot directly containing water and food in the application. And 2 slots on the handle (see Fig. 9, No. 21: slot , No. 23: port) are used for the handle of the pot cover to be inserted directly . When cover handle is directly inserted into slot (21), the cover of the pot is nearly vertically supported, and when cover handle is directly inserted into port (23), the cover of the pot is tilted toward the center of the pot and supported; apart from the supporting function that the cover of the pot can be supported upright, when the cover is supported obliquely, it helps to discharge oil-smoke and vapor (be able to infer the technical effect"); at the same time, it can effectively reduce members on the cover and the difficulty of cover molding. Therefore, these two are very different in structural features and functional effects. (The upright texts are written by the agent, and the italic ones are written by the inventor for the reference of the agent. The draft is still finalized by the agent.)

4. Debate on the Far Infrared Function

"Patent Avoidance" is also adopted in defense analysis to analyze the functions and components of the corresponding distinctive technical features, and "comparative patent" can be understood as "modifying/changing, adding, subtracting and disassembling" the "target patent". The bottom of the pot body in the comparative patent (2) has the same 5-layer structure as that of this application, and is shown in the enlarged analysis schematic diagram of Fig. 12. In the contents on the left of Fig. 12 ([0017], [0019] and [0020] in comparative patent 2, the layers 1 and 5 are made of stainless steel sheet of the "short-wave far infrared pot". Its far infrared emission function has been remained and transferred, and its components are modified/changed into layers 2 and 4 (from top to bottom) of this application with "far infrared functional powder"; layer 2 on the left of the Fig. 12 is the medical stainless steel, and as layer 2 is not in contact with food in the pot, the so-called "medical grade" means excess, which shall be deleted or cut; although layer 5 has the short-wave far infrared function, its material is unknown (potential technical problems). If 430 steel can be combined with layer 4, and if 304 steel is non-magnetic, it shall also be deleted. The first layer of the application is the food grade 304 stainless steel (right of the Fig. 12); the second and fourth layers of the application are far infrared function powder layers (radiation effect) based on tourmaline, the third layer is pure aluminum sheet (heat conduction), and the fifth layer converts 430 stainless steel into magnetized and energized 430 magnetized steel, because 430 magnetized stainless steel has higher magnetic permeability, electromagnetic induction is enhanced so that it can better cooperate with the induction pot to produce a powerful vortex thermal power; at the same time, this magnetized stainless steel can reflect far infrared materials mainly made of tourmaline. When these two kinds of materials are in the same thermal field, these three constitute object-field collaboration, which allows far infrared material layers to radiate more powerful far infrared rays. Therefore, the results of the above analysis and comparison are shown in Fig. 12 (left), which shows that 2 parts of the 5-layer structure of the bottom of the pot in comparative patent 2 have been "deleted", 2 component performances are "modified / changed", and 1 component is "added". The distinctive technical features in the Fig. 12 (right) that makes this invention (5 major effects: electromagnetic induction, heat conduction, reflection, radiation, and co-frequency resonance) solves the potential technical problems of comparative patents, and highlights the powerful cooking functions of the pot. In addition, it's more energy saving and it produces unexpected technical effects. As shown in Fig. 13, functional attribute analysis is applied to investigate the past, present and future performance of the functional analysis, and the product of this patent still has a residual heat utilization function of 5 to 10 minutes even after power failure in the cooking process (The 4th section in the temperature change curve of infrared body of pot is shown in Fig. 13 below): it can be used to steam fish with power cut or fry eggs.

Through the above analysis of functions and components and the application of "patent avoidance", the following shall be added to the opinions on defense in the first audit: "The first functional powder layer arranged on the side wall enables the side wall of the pot to be insulated (for the outside of the pot), to preserve heat, and to conduct heat internally. More importantly, it can be cooperated with the second functional powder layer to comprehensively heat the pot. While heat preservation and ripening of food are realized, the powerful far infrared fully radiated by the far infrared functional material layer of the fully heated pot to resonate with food in the pot under the same frequency, which helps food to be cooked with rich nutrition and well-flavored." Such change not only highlights distinctive technical features, but also displays powerful functions. In addition, it indicates that this application has beneficial distinctive technical features and significant technical effects as well as prominent substantial characteristics.

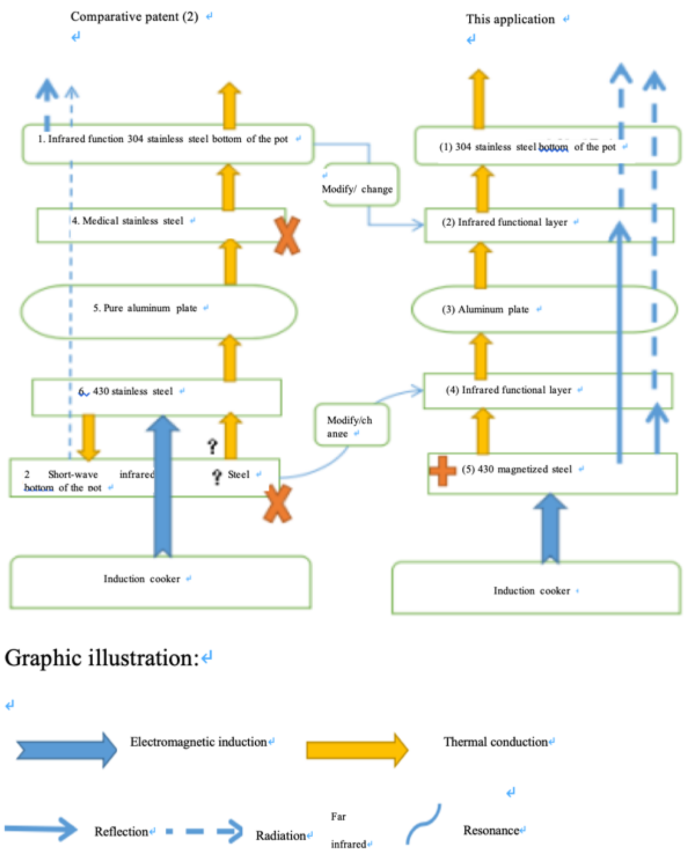


Fig. 12 Analysis and improvement of the structure at the bottom of the pot in the comparative patent (2) and this application

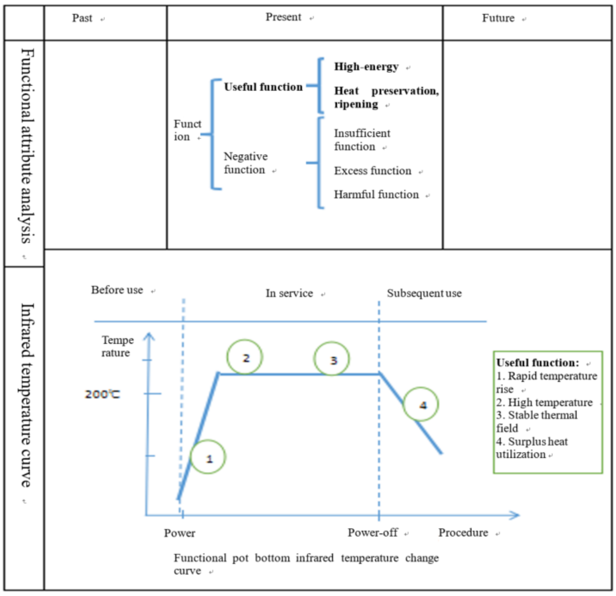
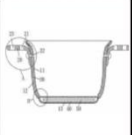
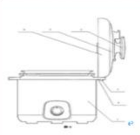


Fig. 13 Analysis of pot bottom's infrared function attribute debate on holistic analysis

The above analysis of functions and components and the application of “patent avoidance” can be briefly summarized in Table 1: the component/principle/function/value of the invention and comparative patents 1, 2 corresponding to the concept of "hierarchy view" are compared and analyzed. Among them, the concept of “hierarchy view” comes from the viewpoints [1] of a Taiwan TRIZ researcher: inventive innovation problem solving can be more innovative at different levels, i.e. component/principle/function/value, meeting at a higher level. “ It’s believed from the learning and application of this theory and patent knowledge that it’s necessary to optimize these two and apply them to patent defense and analysis, of which “component/principle” is equivalent to “prominent substantial characteristics”. That is, the component, position and relationship (principle) of the invention are quite different from comparative patents 1, 2. “Function/Value" is equivalent to "significant progress”. In other words, the pot of the invention has at least 6 useful functions; while comparative patents only have 2 useful functions, but excess function occurs (such as [0020] medical 18-10 stainless steel is used in the inter-layer); there is also the harmful function arising from the pursuit of high thermal field (overheat will be affected by “Curie Point”, 430 stainless steel will be demagnetized, no change within 300 degrees generally, but “fired under 800 degrees for 30 to 40 minutes” in [0027] of this manual); and as shown in Fig. 12, it’s pointed out that the material of pot bottom 2 in comparative patent 2 is unknown, and if it’s made of 304 steel and is not magnetized, this is also harmful. Its value [2] shows that “6 useful functions/1 pot” of the invention is larger than the comparative patent 2 /1 pot（2 useful functions – excess function – 1 to 2 harmful functions). Therefore, the two parts are analyzed and connected to form a “judgment on patent creativity”, which has “prominent substantive characteristics”, and it’s believed that this invention is expected to win and be patented after analysis of patent defense.

Other factors, such as “unexpected technical effects achieved by the invention”, which need to be considered in the judgment of patent creativity are used to judge 5.3 and 6.3 in Chapter 4 of Part II in Guidelines for Patent audit 2010[8], and it's pointed out that when the patent is compared with the existing technology, its technical effects have produced changes of “quality” and “quantity”, which are beyond people’s expectations). From the above analysis, such as in Table 1, on a similar pot, the value of this invention is “6 useful functions/1 pot”, while the comparative patent’s value is (2 useful functions – excess function – 1 to 2 harmful functions) /1 pot. The comparison indicates that: the invention has achieved unexpected technical effects (mainly changes of “quantity” in useful functions), so creativity of the invention is further judged, and it's believed that defense has a relatively large chance of winning the defense.

Table 1 Defense analysis of pot with vertical cover

Patent creativity judgment	**hierarchy view**	Patent – Pot Vertical cover 201610658173.1, technical field; cooking pot, A47J 27/00; technical issues: reduce the loss of nutrition and make food healthy and delicious. Pot cover placement.	Comparative patent (1) - split-type electric pressure pot 201120262125.3, technical field; kitchen appliances, A47J 27/08; technical issues: The pot cover can stand on the outer shell of the electric pressure cooker.	Comparative patent (2) - short-wave far infrared pot 201520071953.7, technical field; cooking pot, A47J 27/00; technical issues: Reduce burnt food and absorption of other smell.
				
Outstanding substantive features	Module: consist of mutual relations and position.	pot handle with jack, pot with extra layers, pot wall with the functional layer, bottom support.	Pressure pot cover with plugs, outer casing of the pressure pot, inner tank.	Pot cover, pot, bottom of the 5-layer functional pot.
	Principles: principles or effects.	Electromagnetic induction, heat conduction, reflection, radiation, Resonance.		Electromagnetic induction, heat conduction, radiation, resonance.
Significant progress	Function: useful or harmful function.	Oblique cover Vertical cover, infrared emission, electromagnetic heating, heat preservation and waste heat utilization.	Vertical cover	Infrared emission, electromagnetic heating. **Excess function:** medical stainless steel; **Harmful function:** pursuit of high thermal field (800 degrees).
	Values: function/cost	**High value** 6 useful functions/1 pot	Low value	**Low value** (2 useful functions – excess function – 1 to 2 harmful functions) /1 pot.
Unexpected technical effects (changes of "quantity" in useful functions), relatively large chance of winning the defense.				
Expected authorization				

5. Defense Results of the First Audit

Through the analysis and comparison of Strengthening and Regeneration of Systematic Patent Avoidance and other methods, it's also necessary to convert TRIZ analysis into patent defense and modify it based on the agent's defense opinions. This case is modified based on Opinions of Statement and added with 30% of the total key quantities. At last, this application was successfully approved after first audit, and the invention authorization certificate of this application was issued by the National Intellectual Property Administration on Mar. 16, 2018.

6. Discussion on Problem Analysis

Based on the comparison of patent application documents and comparative patents in technical fields, problems, effects and features, functional analysis, patent avoidance, patent cutting, hierarchy view, etc. of TRIZ are first used in this paper for deepened analysis of patent defense, in-depth discussion on patent creativity judgment, and evaluation corresponding to "prominent substantial features" and "significant progress" necessary for patent defense is conducted. The purpose is to make the judgment of creativity reflected in the application document more objective and accurate, and it's easier to be recognized by the patent examiners. However, TRIZ application in China has still been at the initial stage, and its application is more concentrated on solutions to engineering technological innovation. The theory itself has been improved constantly, and TRIZ is first applied to analysis of patent application defense in this paper. Although it helps win the defense, points proposed still need more case practice and verification. You are welcome to criticize and correct this paper.

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Zheng Demou, senior engineer and deuty chief engineer of Fujian jinyuanyuan Technology Development Co., Ltd. He graduated from Hefei University of technology in 1976. In 2012, he began to receive TRIZ training. In 2014, he has obtained patent authorization of "an improved design method for the base of table top water purifier applying TRIZ" (cn201410781798.8, cn201410781799.2), and application of "the structure and design method of boiler based on TRIZ" (cn201410806978.7). Since 2015, recommended by Fujian science and Technology Association of China and other departments, it has successively undertaken basic and upgrading training of enterprise innovation methods in Pingtan Experimental Zone, Fuzhou City, Xiamen City, Anxi County and Fuzhou University, with more than 500 trainees. Since 2018, he has participated in the 8th-10th global system innovation competition (GCSI) and the 9th-11th International Conference on system innovation (ICSI) three times, and won silver award and excellent thesis award twice. From 2018 to 2020, he participated in Fujian Taiwan Innovation Methods exchange meeting (Xiamen, China) three times and made keynote speeches. Since 2014, individuals and innovation teams have applied TRIZ to create more than 259 invention applications, including 31 authorized inventions. Since 2017, it has undertaken the innovation method application project of the Ministry of science and technology of China for the second time, and has obtained more than 1.2 million yuan of scientific research funds.

Xu Daohua, chairman of Fujian OSPRING Technology & Development Co., Ltd., with more than 30 years of experience and leadership in the field of applied physics and water treatment technology, is a famous expert and entrepreneur in China's health function water industry, and an excellent entrepreneur in Fujian Province.He has participated in the Chemiluminescence Test Group of National 863 Project. Now he is the director of China Invention Association, the member of Expert Committee of China Health Care Association, the vice president of Fujian Intellectual Property Association, and the vice president of Fuzhou Enterprise and Entrepreneur Federation. He is also the leading expert of China health function water industry standard, the standing director of China Invention Association, the member of the Expert Committee of China Health Association, and the member of the Financial and Economic Committee of Standing Committee of Fuzhou Municipal People's Congress. He has won the 2016 National Advanced Individual in Intellectual Property Work, the Fourth National Award for Invention and Entrepreneurship, two gold and one silver awards in the Sixth International Invention Exhibition, and "Top Ten Scientific and Technological Workers" by China Health Care Association. In addition, he is also one of the top 50 of China Central Television's "I am an Inventor" campaign. Up to now, he has personally participated in more than 400 inventions. Under the leadership of Xu Daohua, Fujian OSPRING Technology & Development Co., Ltd. has been successively awarded the following honors and titles: National Intellectual Property Advantage Enterprise, Fujian High-tech Enterprise, Fujian Innovative Enterprise, Fujian Famous Trademark, Top Ten Creditable Brands in China Health Care Industry, etc.

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Zheng Qin, R&D manager of Fujian Ospring Technology Development Co., Ltd., master's degree. In 2016, he graduated from Fuzhou University and began to receive TRIZ training and practical application. Till now, he and his team have created more than 88 patent applications (including 33 invention patent applications) through TRIZ. In 2020, he participated in the Special Project for Innovation Method Application of China's Ministry of Science and Technology.

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A Strategic Model of Innovation

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Abstract

The academic literature provides many models of the innovation process, often based on the 'innovation funnel'. Experience from earlier research has shown that these models struggle to define innovation as a process at the strategic level or provide ways to measure innovation effectiveness. A strategic model of innovation was developed to address this gap based on the methodology International DEFinition method (IDEFØ). Modelling innovation as a hierarchical, standardized process conforming to the strict discipline of IDEFØ resulted in an improved understanding of the innovation process. It enabled a more robust measurement of the company-wide impact of innovation support activities; in this research case measuring the benefits of adopting TRIZ tools.

Since the original work, this strategic model has been applied to diverse fields including Fast Moving Consumer Goods (FMCG), Automotive, Agriculture, Fisheries, City Planning and Sustainability. Learning from these experiences has informed refinements to the model such that it now provides a coherent, top-level understanding of innovation as a strategic process.

The key takeaway is that innovation is more than introducing new products and services; it is closely aligned to business strategy, encompassing all business activities. The proposed innovation model emphasizes the importance of intangibles. It also addresses the contradictions inherent in embedding sustainability within business and in society more widely. A valuable benefit of the proposed model is that it contextualizes discrete innovation programmes within a holistic framework. This paper describes the model and its practical application in framing Systematic Innovation programmes including TRIZ and TrenDNA. An example is provided, asking the strategic question - is the world really transitioning to electric vehicles, and if so, when?

Keywords: Business Strategy, Electric Vehicles, IDEFØ, Innovation Model, Sustainability

1. Introduction

Avon Vibration Management Systems (now DTR VMS) is a world leader in automotive elastomeric chassis and engine mounting systems, with several world firsts. Engine mounting systems manage loads, articulation/travel and vibration isolation under extreme working conditions.

In 2004 a research collaboration between Avon VMS and the University of Bath aimed to introduce TRIZ as a methodology to improve innovation (Frobisher, 2010). In common with automotive industry practice, the company used Six Sigma as an improvement philosophy. Projects were conducted within the DMAICT framework (Define, Measure, Analyse, Improve, Control, Transfer). This prompted the question – how to Define and Measure innovation?

Definitions of innovation found in literature were centered around various wordings and interpretations of 'the commercial application of new inventions'. Whilst this was obvious, the DMAICT approach for process improvement requires more than a top-level description of the process – the 'what'. It requires a comprehensive understanding of the process itself – the 'how'. This necessitated a review of detailed innovation process definitions and models. These were found to be overly focused upon ideation, creativity and invention and unsatisfactory for the purpose of the project. A suitable innovation process model was therefore unavailable, and one needed to be created.

This paper describes a model of innovation, based on the IDEFØ modelling approach, that was derived and applied during the project with Avon VMS. The benefits of using this comprehensive innovation model to guide innovation activities are discussed, and the potential benefits for TRIZ and Systematic Innovation practitioners identified. The application of the model is demonstrated through a case study of innovation in the electric vehicle market.

The novel contribution to the body of knowledge that this paper contributes is that:

•The innovation process can be decomposed into hierarchical functions

•Innovation sub functions are shown to transcend departmental and even inter-company boundaries

•The IDEFØ model of innovation is scalable from the company level to entire economic sectors

•The IDEFØ model supports the TRIZ approach to innovation, identifying contradictions

•Innovation is a holistic process that includes operations and end use of the product or service

Section 2 of this paper provides an overview of typical innovation models, grouping them in the domains of design and management. Section 3 is an introduction to the IDEFØ methodology. Section 4 applies IDEFØ to the innovation process with an example applied to the electric vehicle market. Section 5 discusses the implications of the work and Section 6 draws conclusions and recommendations for further research.

2. Typical models of innovation

The existing innovation literature was reviewed in order to identify relevant models of the innovation process. Models were identified from two different domains: the design domain, and the management domain.

Starting with the design domain, a commonly cited model of the innovation process was developed by the UK Design Council (2007), which is known as the 'double diamond' – shown in Fig.1. The model splits the innovation process into four phases that alternate between divergent exploration and convergent activities. Significant emphasis is placed on developing a better understanding of the problem through the 'discover' and 'define' phases, such that a precise problem definition and design brief can be formulated. The 'develop' phase then explores the potential solutions to the defined problem, before a final solution is selected and introduced in the 'deliver' phase.

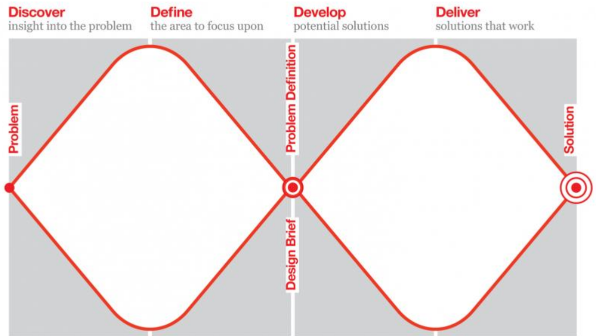

Fig. 1 Double diamond model of the innovation process (Design Council, 2007).

Another widely cited innovation model is 'design thinking'. Popularized by the Stanford d.school, this model, shown in Fig. 2 shares similarities with the double diamond model in terms of the overall process, but places more emphasis on understanding the user of the product or service in the 'empathize' phase, as well as on prototyping and iterative improvement of the design during the development of the final solution.

The influence of the design thinking process model and key principles can now be seen outside of the design domain, in areas such as information technology and business management, Dorst (2011).

These models, which represent innovation as a sequential process, have proven popular with innovation practitioners, which may be because they represent the innovation process as experienced at the operational level i.e. as a series of activities that each help to progress towards the completion of a defined, discreet 'project'. However, the limitation of these innovation models is that they do not provide a complete overview of the factors that influence innovation activity as a strategic business process.

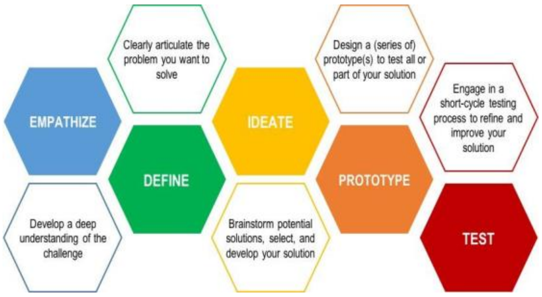

Fig. 2 'Design thinking' model of the innovation process (Brown.T , 2009).

Looking next at the models of innovation from the management domain, the model presented by Tidd et al. (2005), shown in Fig.3 is typical of the management perspective of innovation. Whilst the core process of 'search, select, implement' is very similar to the sequential models from the design domain, there are key additions. For instance, the strategic context of the organization is now explicitly represented as an influencing factor. Also, the importance of learning and improvement over time is shown, with the idea that the organization is progressing towards becoming an 'innovative organization'. Hence, from the management perspective, there is less emphasis on the individual project, and more emphasis on the activities and performance of the whole organization.

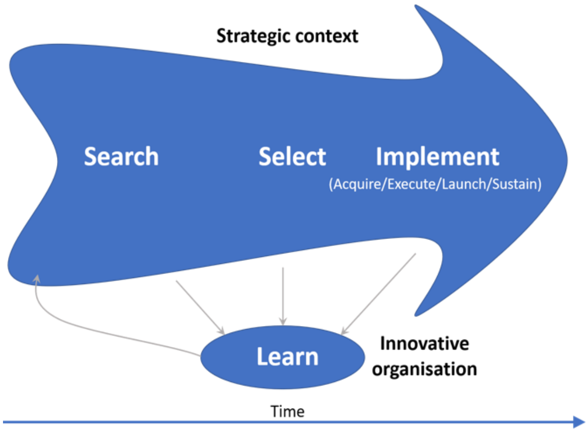

Fig. 3 Typical model of the innovation process from management domain (Tidd et al, 2005).

This more holistic view was a key aspect of the work by Stafford Bear in 1960s, who developed the 'Viable System Model' (VSM) as part of his cybernetic theory of organization, Bear (1972). VSM was intended to help describe all aspects of an organisations activities, including innovation. The model, shown in Fig.4 proposes five essential 'organs' that make up any autonomous, self-sustaining organization: the operational organ (S1), the coordinator organ (S2), the controller organ (S3), the planner organ (S4), and the policy organ (S5).

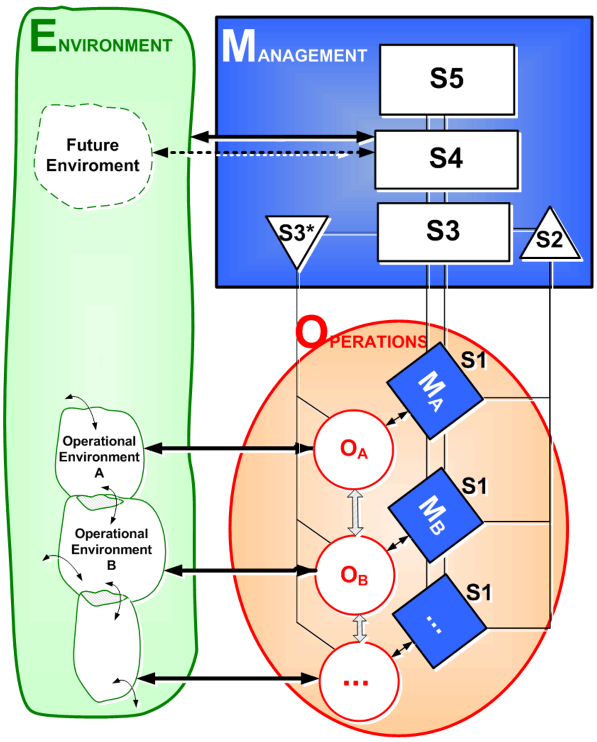

Fig. 4 Viable System Model of the organization (Bear, 1972)

Key aspects of VSM include an emphasis on the interaction between the organization and the external environment, the need to predict and respond to future changes, and the need for communication between all functions to ensure the success of the system. Whilst VSM provides a comprehensive and holistic model of the organization, it is perhaps more theoretical and less intuitive or practical as a support to inform and guide innovation activities.

What this brief review has shown is that the models of innovation from the design domain offer a practical, project-based perspective of the innovation process but typically do not sufficiently consider the context of the project in terms of the wider organization or the external environment and do not consider the changes that occur within them. These elements are considered to some extent in the innovation models from the management domain, but none of the existing models incorporate all of these elements and present them in a way that offers practical guidance or insight that can help innovation managers. The aim of this paper is to address this knowledge gap by applying the IDEFØ modeling approach to develop a comprehensive and practical model of innovation.

3. Introduction to the IDEFØ method

IDEFØ is a functional modelling approach developed by US Air Force Materials Laboratory in the 1970's. In the 1980's it was used to model the US military supply chain. Any process can be modelled using the IDEFØ convention, 'ICOM' – Inputs, Controls, Outputs, Mechanisms.

According to the method, verbs/functions are contained in boxes and are fed by arrows which are nouns – things, including data and information as well as physical objects and substances, as shown in Fig 5.

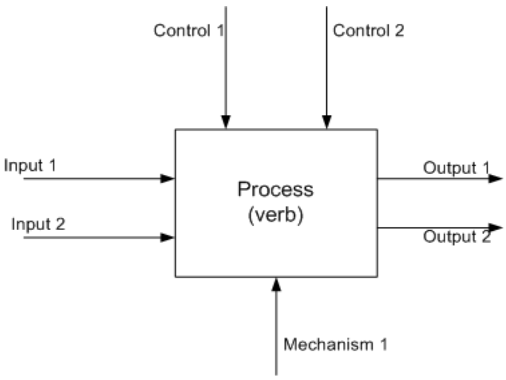

Fig. 5 IDEFØ ICOM process box.

Inputs are transformed or consumed by the process - e.g. raw materials, data or energy

Controls specify the conditions for the process to produce the correct output

Outputs are the data or objects resulting from the process.

Mechanisms are the means and resources which support the process.

Each process can then be decomposed into sub processes at increasing levels of detail in a hierarchical structure as described in Fig. 5.

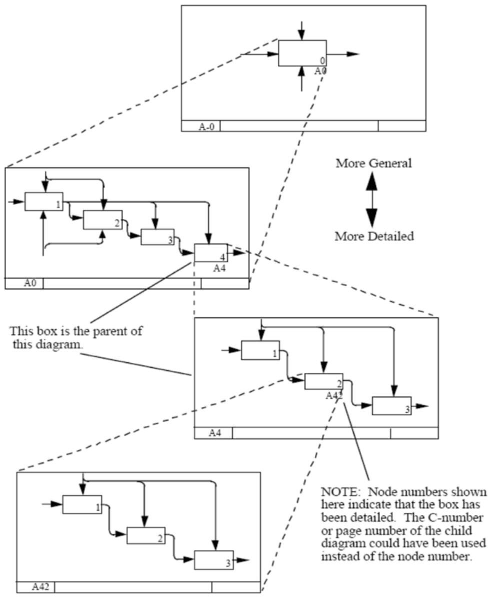

Fig. 6 IDEFØ decomposition model structure (KBSI, 2005).

The A-0 level enables the modeller to communicate the context of the system, and the A0 diagram shows the top level of the process (the reader is directed to note the distinction between 'A-0' and 'A0'). The decomposition of the boxes also applies to the arrows, which sub divide at lower levels – so 'data' may comprise invoices, schedules, designs and so forth at lower levels. The arrows into and out of a lower level box must remain consistent with the arrows at the higher level.

It is also important to note, that in common with the 'organs' of the Viable System Model shown in Fig. 4, processes are not strictly sequential, although they can be considered in this way. It is more akin to looking a circulatory or nervous system. This contrasts with the sequential mindset of the design paradigm of innovation.

The IDEFØ modelling approach promotes deep questions about the nature of processes, expanding the mindset outside of departmental structures; with a TRIZ-like focus on function. In the next section, we apply the IDEFØ modelling approach to the innovation process.

4. An IDEFØ model of innovation

The IDEFØ method requires that each box contains a verb that describes a process. ‘Innovate’ is a verb and is therefore a valid process for IDEFØ definition and modelling.

At the highest hierarchical level, Fig. 7 is the A-0 context diagram for the ‘innovate’ process, showing the top-level inputs, outputs, controls and mechanisms.

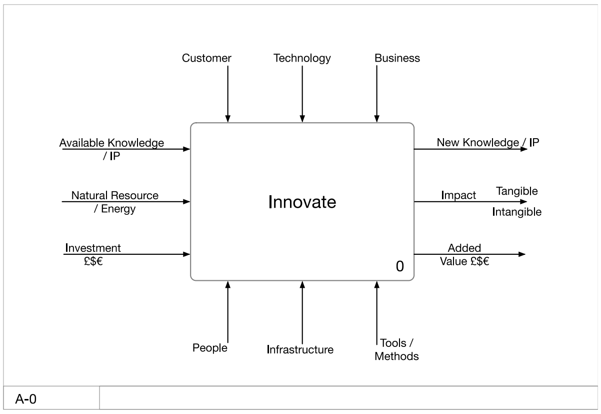

Fig. 7 Innovation A-0 context diagram

There are three categories of inputs: available knowledge and Intellectual Property (IP), natural resources including energy, and investment. Through the innovation process, these inputs are transformed into the outputs of: new knowledge and IP, impact (tangible and intangible) and added value. Of these outputs, it is the impact aspect that merits further discussion.

Typical models of innovation tend to focus on the tangible outputs of a single innovation project in terms of the new products/services delivered and the monetary added value for the business. In this IDEFØ model, the term ‘impact’ is used to encompass both these tangible impacts as well as the intangible. Furthermore, it is important to consider all impacts of an innovation process, both positive and negative. This broad definition of impact leads to categorization and examples of ‘impacts’ shown in Table 1.

Table 1 Innovation output – impact.

Positive Tangible	Positive Intangible
• Increased sustainability • Satisfied customer needs (jobs done) • Products performing safely and to specification • Improved health, safety, wellbeing • Increased wealth and financial security • Economic stability • Employment	• Societal benefit • Pride, surprise, delight, WOW! • Happiness, contentment • Love, acceptance, belonging • Nostalgia • Feeling ‘in on things’ • Sense of progress • Good reputation • Meaning
Negative Tangible	**Negative Intangible**
• Carbon footprint • Environmental pollution, contamination • Waste, faulty goods or services • Harm, risk to people (customers or employees) • Unsustainable consumption • Financial – expense • Economic disruption	• Societal Harm – e.g. unintended consequences • Shame, embarrassment • Fear, shock • Hate • Anger, rage • Frustration • Bad reputation • Injustice

The outputs in Table 1 are by no means comprehensive. TRIZ practitioners will notice a similarity with the ideality equation; with positive outcomes set against costs and harms. Good innovation output means more good things and less cost and harm, achieved by breaking contradictions – for instance reduced environmental impact whilst simultaneously satisfying consumer needs.

The mechanisms of innovation (sometimes referred to as ‘means’), include ‘people’, ‘infrastructure’ and ‘tools/methods’. People are the primary means of innovation and, as we shall see in the next section, ‘people’ includes those in the supply chain, at all levels and functions of business, and customers/consumers. This is in contrast with the prevailing assumption that innovation is conducted by designers, scientists, engineers and marketers.

People require an infrastructure to work within – buildings, machines, software, communications, transport and includes the supply chain.

People also require tools and methods to efficiently organize. This includes management systems and methodologies, innovation tools such as TRIZ, production process improvement tools such as Six Sigma and Lean, and physical test methods such as validation test protocols.

Finally, considering controls, there are three sources of requirements and constraints that together shape the outputs of an innovation activity. These are ‘customer’, ‘technology’ and ‘business’. The importance of understanding customer needs - whether explicitly expressed or implicit/unconscious - is exemplified by the design and business innovation paradigms and marketing disciplines. Even ‘new to the

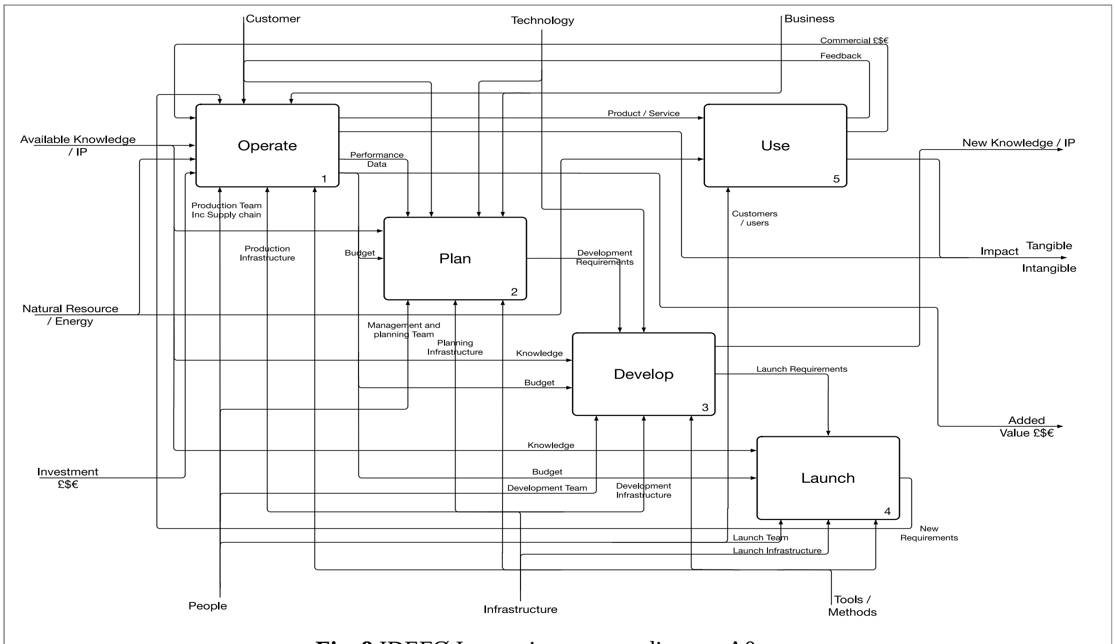

Fig. 8 IDEFØ Innovation process diagram A0.

world' products will make use of existing technologies (such as production technologies) and must therefore take account of the limitations and constraints that those existing technologies impose. These 'technologies' can be categorized within the domains of Physics, Chemistry, Biology and IT/communications. The business performing the innovation activity also generates a number of constraints, such as the need to comply with regulatory requirements, meet legal obligations or satisfy the overall strategy of the business, which may be to make strategic moves in relation to competitors or deliver an exit strategy.

So far, at the A-0 context level, the range of issues addressed by the IDEFØ model of innovation show considerable overlap with those covered by the typical models of innovation described in Section 2. The main novelty of this approach to understanding innovation is that managers should consider the tangible and intangible, positive and negative impacts and not just the product delivered and the financial added value. However, it is when we dig down into the next level of decomposition that we start to unearth some interesting insights.

Fig. 8 shows the A0 IDEFØ diagram for the 'innovate' process, which reveals the sub-processes and the next level of connecting arrows (not all arrows shown). The main sub-processes are 'operating the business', 'planning the business', 'developing new things', 'launching new things', and 'use of the product or service'.

The design paradigm models of innovation tend to focus on processes Plan, Develop and Launch. In contrast, the IDEFØ model brings in processes Operate and Use into the innovation process context.

Operation provides the finance to support everything else. Even in a start-up, it is an operational process to secure investment. In established companies the organization must decide what proportion of the financial output of the operations function should be taken as profit (added value) versus developing, improving and implementing new processes within the operations function, as well as new products and services. This is a strategic decision.

Other than investment or external funding, Operation depends on receiving money from customers, and therefore Use comes within the innovation process. Again, this is a point of difference with the typical view within both design and business paradigms that customers are external to the innovation process.

In practical use of this model, it has been found that the sub-process boxes hold true at any organizational scale. It holds at the level of a department, business unit/profit center, industrial sector or even at the national governmental level. It can therefore be considered generic. The hierarchical level context becomes more specific when considering the arrows.

When using IDEFØ to represent an innovation activity, modelers have to use judgement so as to present the IDEFØ diagram in a suitable manner for the context and purpose of the work. Whilst all flows of knowledge, resources and investment can in theory be represented, it is better to focus on the most important. Even with some pruning, Fig. 8 serves to demonstrate the many interlinkages between the sub processes and why innovation is such a complex process to manage; encompassing so much of what an organization does. We cannot go into the detail of each arrow, but discuss some key insights from Fig. 8 here.

Who does innovation? The traditional view would be those contributing to the Plan, Develop and Launch processes. But this is the wrong question. The model shows that it is not individuals but the organization that does innovation. The right question is “Who contributes to the innovation process?” And that is everyone – including the operations function and customers. The People arrow subdivides into the operations team, the planning team (often senior managers), the development team (specialists, technical and marketeers), and the launch team (mixture of project managers, technical and production/operations people). Finally, there are the customers and end users on which the whole innovation system depends.

From a traditional innovation managers perspective, the takeaway is that many of the people that affect innovation are outside of your direct control, and some you don’t even know about - particularly in the supply chain and end customers. Hence, the spectrum of disciplines, perspectives, priorities and personality types required to successfully manage and deliver innovation is extremely diverse and often contradictory. This perhaps explains why so many innovation attempts fail.

Another interesting insight is that the Impact is influenced by the nature of the operations and the end use of product and service. The tangible dimension includes, for instance, the environmental impact of the production facilities, including the supply chain right back to the mine or farm. Sourcing and purchasing strategy can be influenced by organisations to minimize negative imp acts, but also the innovation process itself can seek to balance or break the contradictory requirements of innovation controls – consumer needs, technology, and the businesses financial realities, regulatory/legal and competitive landscape. It is also important to note that the way customers use and dispose of a product is part of the responsibility of the innovation process which represents an innovation challenge in itself.

From this brief introduction, it is clear that applying the IDEFØ methodology to model the innovation process provides a model that is both comprehensive and also able to provide fresh insights and perspectives of innovation. The IDEFØ model can also be used to forecast future developments at a sector level. A case study has been developed of the IDEFØ model applied to the automotive sector, considering the transition to electric vehicles (EVs). The A-0 context diagram is provided in Fig. 9 whilst the full case study is available at: https://strategic-innovation.co.uk/electricvehicles.

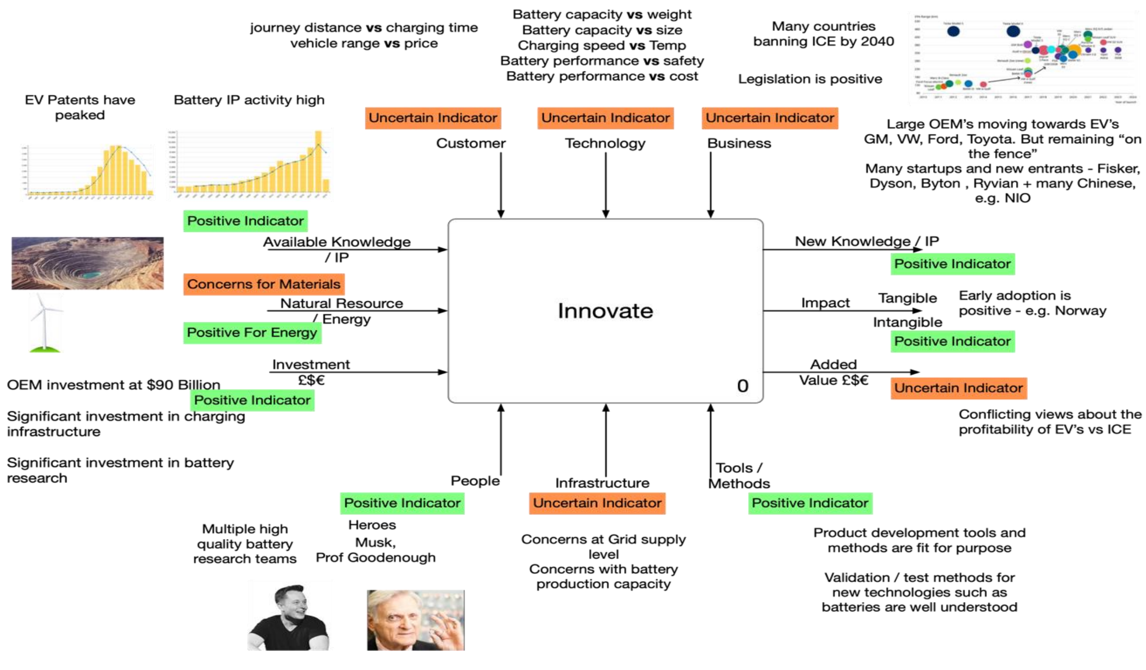

Fig. 9 Summary of the A-0 diagram applied to the context of EV adoption in the automotive industry.

In brief, the finding is that the most important contradictions to be solved for EV adoption are primarily within the battery domain. It appears that sufficient investment is going into solving the right problems such that, if resolved by the talented teams working in the area, it should flip the majority of the industry to producing full electric EV's, perhaps more quickly than some will be expecting.

Further recent publicly available examples of use of the IDEFØ model applied to the fisheries sector are available; Techau et al, (2020) and Sala Antonello et al, (2020).

5. Discussion

The majority of models for innovation and creativity, such as the double diamond or design thinking models, use a sequential approach to creation and management of ideas or concepts. These models are not wrong, and are powerful tools for their purpose, especially in understanding the voice of the customer. However, as evidenced in the original research, these do not sufficiently provide insight in the broader strategic setting because they are sequential not hierarchical.

Strategic models that are none sequential, such as VSM, tend to focus on the top level and are suitable for understanding the voice of the business for strategic planning, but are not suited as tools for management of innovation processes.

There appears to be a need for a model that can be both hierarchical and sequential. At the A-0 context level, the IDEFØ model is non-sequential and hierarchical. At the A0 level, the IDEFØ model can be both sequential and non-sequential. The IDEFØ model therefore offers a potential solution to this contradiction.

5.1 TRIZ / Contradictions

TRIZ theory emphasizes the importance of resolving contradictions to solve the right problems. There are TRIZ based approaches for each of the IDEFØ A-0 controls – TrenDNA (Mann, 2009) for consumer, Classical TRIZ for technology and Business TRIZ for business. The competing and conflicting requirements that emerge from these three different perspectives can be viewed as a source of contradictions by the TRIZ practitioner. As an example, taking price, we can see that there is a contradictory requirement for the business to seek a high price, conflicting with customers who require a low price. This contradiction can be solved by applying inventive principles or evolutionary trends to resolve technical challenges, enabling maintenance or enhancement of the functions that customers require to be delivered, whilst using fewer inputs thus reducing costs.

5.2 Measuring Innovation

The IDEFØ model could potentially be used to refine approaches to measuring innovation. One approach would be to measure the ratio of inputs to outputs – the size of the jump. How effectively does the organization gather and manage available knowledge/IP and transform this into new knowledge/IP? How well does the organization turn investment into added value? How effectively does the system, including the supply chain and end users, turn natural resources and energy into tangible benefit? Existing approaches appear reasonably well established to measure these tangible outputs/ratios. The primary gap appears to be measuring and understanding intangible output.

It is a common criticism of the capitalist system, that businesses put profit above everything. The reader may agree or disagree with this premise depending upon where on the political spectrum they sit. However, what should be agreed is that one reason this may be true is that money is easier to measure than emotion. Steve Jobs is famously quoted as saying, “I want to put a ding in the universe”. In common with many entrepreneurs, such as Elon Musk, Jobs wanted to make a difference and leave a lasting legacy – a positive innovation footprint, which is far more than a purely financial motive.

Intangible impacts are currently the domain of marketeers - branding and market research. However, the wider reputation of the organization, within society, politics, media and industry is not fully addressed as yet within the innovation strategy community. The unintended societal consequences of advances in technology do not seem to be responsibly considered or even understood, never mind addressed. This is evidenced by the debate concerning social media and its effect at the individual level (in terms of mental health) and at the societal level (in terms of political influence).

Fortunately, the science of measuring intangibles is developing. Software based approaches such as Pansensic (www.pansensic.com) are making substantial progress in this area – being able to map and track emotional content such as frustration, fear, delight and love.

Companies that are interested to learn more about the legacy they are building and their intangible impacts should ask themselves the question: “if we were to delete our company, would we be missed?” Being able to track how such intangible aspects of Impact change over time may allow leaders to steer organisations using more than the existing financially skewed performance indicators.

5.3 Sustainability

There is an increasing urgency to address global environmental challenges. The IDEFØ model emphasizes to individual companies that their innovation impact (footprint) includes their direct environmental impact but that they also have a responsibility to manage the impacts of their supply chain and the behavior of customers.

The hierarchical approach of the IDEFØ model also allows analysis at the industrial sector level, giving policy makers an insight into the nudges and frameworks required to successfully align the value-add financially oriented output arrow with sustainability objectives.

5.4 Managing Innovation

Insights related to tackling relevant contradictions and managing knowledge have already been covered in this paper. From experience, most companies are not short of great ideas, the issues are the selection and combination of the right ones and implementing them effectively.

Project managers will testify that introducing new products and processes creates a tension, or even outright interdepartmental warfare, between the operations teams of process 1 (Operate) and those of process 4 (Launch). Perhaps this is at least partly because operations, in many companies is considered separate to the innovation team, and is set up, financed, measured and managed accordingly. Organisations need to find better ways to unite the entire enterprise within the innovation framework. Everyone in an organization contributes to innovation in some way, whether they realize it or not. This perspective appears to be relevant to the subject of 'innovation capability'; managing systems to be able to successfully make step changes either as a leader or follower in a given marketplace. See fig. 10

At the sector level, the introduction of new things, tends to require the destruction of something to make room – 'creative destruction'. The challenge therefore is to introduce 'managed destruction' – ideally by designing markets and sectors that are set up to renew themselves with minimum overall harm. Companies need to plan for step change disruption, as opposed to steady state or incrementalist thinking. This includes considering financial models, workforce skills/flexibility and how they co-operate and compete with other players.

Innovation models from the management domain such as VSM are used to develop strategy, Hoverstadt, (2017). In contrast, design paradigm models suggest that innovation projects are discrete activities that contribute to a given strategic direction. The IDEFØ model indicates that the innovation process itself has a much wider scope than that of the design paradigm and shares a similar scope to VSM. A key insight from this research therefore, is that the innovation process could be considered closely synonymous with strategy.

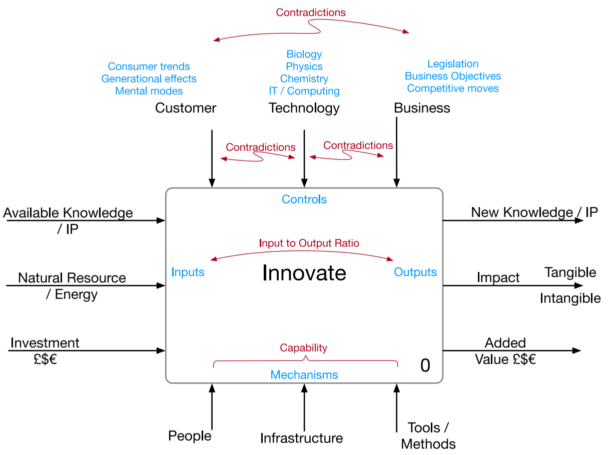

Fig. 10 Summary of the A-0 context diagram applied to measuring and managing innovation.

6. Conclusions

This paper started out by identifying the range of existing models of innovation identified within the design and management communities. Some models from the design domain provide a sequential view of the innovation process and are good at showing the main activities of innovation but do not show the strategic or contextual influences. Models from the management domain address the strategic context but are too abstract to be of real benefit to practitioners. It was proposed that a model of innovation based upon the IDEFØ modelling approach could address this gap.

Through the presentation of the generic IDEFØ model of innovation and its application to a case study, it has been shown that the IDEFØ innovation model offers the potential to harmonize the sequential, project based innovation models of the design paradigm with the hierarchical models from the management domain. Key insights from the application of the model include the idea that innovation has a wider scope than is traditionally assumed – and includes operations, supply chain and end users and that all 'people' within the system, including employees, suppliers, customers, regulators etc. contribute to the innovation process. More generally, the model raises the idea that because of this wider, holistic definition, the innovation process is closely synonymous with strategy.

Within the innovation consulting activities of the author, the practical application of this model so far has been to create an appreciation of the connected nature of innovation programmes at clients and how everything fits together. It has also proved useful in developing a holistic view of an economic sector to estimate the propensity for a disruptive 'jump' – as demonstrated in the electric vehicle case study.

Future research activities that may benefit from adopting the IDEFØ model of innovation might include studies concerned with the measurement of innovation attempts relating to the broad definition of innovation 'impacts' provided by this model and the ability to apply the model at different systems levels (e.g. business units, whole companies or whole industries). The model could also be helpful as the basis for a study of success and failure factors for innovation, as the ability of the model to represent the innovation activities of a company in a comprehensive manner should ensure that all aspects (both internal and external to the company) are considered. Finally, the implication of this research to the alignment of sustainability and circular economy objectives with business strategy and product development should be further considered.

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Analysis and Application of Energy Management in Industry 4.0 with TRIZ Methodology

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Abstract

The advent of Industry 4.0 takes our understanding of technology to a whole new level. The pursuit of profitability is gradually being replaced by business strategies that focus on comprehensive and sustainable operations. As a consequence, the looming energy crisis has become the center of attention, making smart energy management solutions an indispensable cornerstone of industry transformation. For intelligent factories, in addition to upgrading manufacturing equipment, businesses can improve upon traditional models of energy management by collecting and analyzing big data generated by the equipment. Smart energy management, in sum, is a system that effectively coordinates, monitors, integrates, manages, and predicts the operation of multiple sets of equipment, creating a customized energy management platform for every business based on data analytics. The present study is a case study on the facility management system adopted by semiconductor manufacturers. The author discusses the developmental trends in smart energy management within the context of Industry 4.0 based on "failure modes and effects analysis (FMEA)" and the "theory of inventive problem solving (TRIZ)." Building on the results, the author summarizes the potential technologies that meet practical needs and the development of intelligent electrical components that address potential failure modes. Finally, through the application of Internet of Things (IoT) and big data collection and transmission, businesses can conduct predictive maintenance on their in-service equipment to prevent system downtime, realizing the true benefits of intelligent management. The author hopes that the findings of this study can offer useful insights for relevant industries seeking to transform their businesses intelligently.

Keywords: Industry 4.0, TRIZ, FMEA, IoT, Big Data

1. Introduction

With the advances in sensor technology and the increasing penetration of Internet of Things (IoT) devices, the integration of communication and sensor technology has become the key driver for the manufacturing industry's foray into smart manufacturing. Taiwan has transformed its early labor-intensive processing industry into the capital- and technology-intensive OEM industry of today. With the rapid changes in market dynamics, the industry's long-standing advantage is now threatened by other Asian countries, causing a slowdown in the industry's growth. To venture into smart manufacturing, the Taiwanese manufacturing industry needs to transform itself through changes in its manufacturing environment and capacity, along with development in energy and resource allocation. To counter the competitive pressure and changes in external environment, the industry needs predictive analytics skills to improve its operational efficiency and competitive advantage in manufacturing, marketing, and information technology.

Thriving industrial development drove the high emission of greenhouse gas and intensified the energy crisis. Operational objectives for businesses has begun to turn from past emphasis on profit and growth to comprehensive sustainable development strategies. The manufacturing industry implemented reactive maintenance in the past but has moved towards predictive maintenance in recent years, analyzing the large amount of data generated in the manufacturing process to make further predictions; smart energy management is also enhanced to achieve effective energy distribution, low energy consumption, and equipment efficiency optimization. For example, through the implementation of built-in power monitoring sensors in transformers, power system monitoring can detect network abnormalities and perform instant shutdown of equipment affected by tripped circuit breaker, power outage, or electrical issues. Few studies have focused on the practical application of power monitoring equipment in smart manufacturing, which can boost industrial transformation and gives the industry a competitive edge.

This study is focused on the developmental history and significance of Taiwan's industrial transformation from processing to OEM and its future developmental trend in smart manufacturing. Boosted by the integration of IoT, big data analytics, and smart energy management, the industry shall venture into smart manufacturing. TRIZ-based empirical analysis of smart energy management shall be based on smart power monitoring equipment to accomplish an improvement in manufacturing efficiency via preventive maintenance; the Internet's role in factory management system is further discussed.

2. Literature

Taiwan transitioned from an early agricultural society to a fast-growing light industrial society in the 1960s, producing electronic, textile, and plastic products. Taiwan further started development of strategic high-tech industries in the 1980s to accelerate industry upgrade and ride the wave of global industrialization. Despite the fact that recent development in smart manufacturing has outpaced the past growth of industrial automation, the years of accumulated experience in industrial transition and explosive growth in knowledge gained over the past 20 years allow the industry to draw on past experiences for an expedited way to determine solutions. By establishing a problem-solving approach towards management, technology, or operations on the wisdoms of our predecessors, we are no longer bound by existing framework of thinking and can identify the root of our problems via innovative theories, thus leading the technological development of Industry 4.0 and smart manufacturing.

2.1 History and significance of Taiwan's industrial development

The early economic development of Taiwan is built upon its agriculture and light industry. Boosted by the government's Ten Major Construction Projects and its support in key industries, Taiwan accelerated its industrial transformation and improved its competitiveness, gradually developing into a small capitalist economy that draws investment through small and medium-sized businesses. The Taiwanese economy has continued its steady growth in various aspects. The manufacturing industry accounts for the largest percentage in Taiwan's GDP. Among them, the telecommunication and high-tech manufacturing sectors started with traditional computers and video game consoles and moved on to the rapidly-developing laptop market. This, coupled with the rapid development of the venture capital market, established Taiwan as a global hub for semiconductor foundry, packaging/testing, and system engineering, while laying the solid foundation for the optoelectronic industry of solar panel and display panel.

(1) Innovative industrial significance - smile curve

The government encourages new forms of technological R&D and international trade opportunities to stimulate demand and raise awareness for industrial transformation among the domestic manufacturing industry. New ideals and values are therefore the cornerstone for brand development. Market demand and innovative thinking are two concepts of the infrastructure industry, the former concerns the customized demand of clients (patent, technology) and the latter is about ideals and beliefs in the managerial aspect (brand, service). This model corresponds with the smiling curve theory proposed by Acer Group founder Stan Shih in 1992, which divides the industry value chain into three parts: patent & technology, manufacturing, and brand & service. The curve represents value-added, which is low in the middle part and high on the two ends. This theory suggests that for a business to increase its profit, it has to reorient itself into the two ends instead of continuing development in manufacturing. For innovative R&D thinking, one must first find the corresponding market demand through which innovative value can be identified, and a continuous implementation of innovative thinking can be carried out. This is expected to create value through technological innovations of information evolution.

(2) The innovative management model of the high-tech industry in Taiwan

Open innovation is a new form of operational model that has been drawing large attention. The term "open" refers to the model's contrast with past models, which focused on internal innovations without considering external situations. In a closed innovation model, enterprises can only profit through innovations by hiring the best employees and technicians. The open innovation theory facilitates flows across enterprise boundaries for existing internal technologies of an enterprise and external technologies relatively unrelated to the enterprise's business operations (see Fig.1). For example, at the Taiwan Semiconductor Manufacturing Company (TSMC), designers can utilize the open innovation platform to integrate the relationship between upstream IC design clients, IP core partners, and the semiconductor design ecosystem and create a whole new business model for the semiconductor industry. This can help shorten the design-to-manufacture time of products and connect the company's core competitive advantages in technology, manufacturing, and clients (see Fig.2).

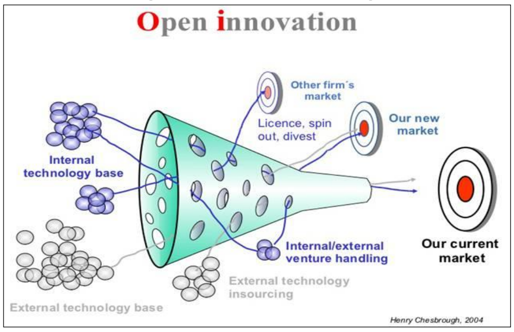

Fig.1 Open innovation
Source: (Henry Chesbrough, 2006)

In recent years, TSMC has been focused on the business opportunities of IoT and wearable technology. The company implemented an ultra-low power consumption technology platform and created a comprehensive design ecosystem that combines mobile communication chips and semiconductor manufacturing with vendors of computing/sensing equipment and communication technology, so as to support the IoT applications of ultra-low power consumption technology. When designing a new manufacturing process for advanced technology, chip designers can utilize TSMC's IP core database for low power consumption technology to improve the success rate of design and manufacturing. Additionally, TSMC also provides various related applications on the technology platform, which can facilitate the R&D of competitive products and shorten time to market. This open innovation platform is expected to bring about another wave of technological growth at TSMC.

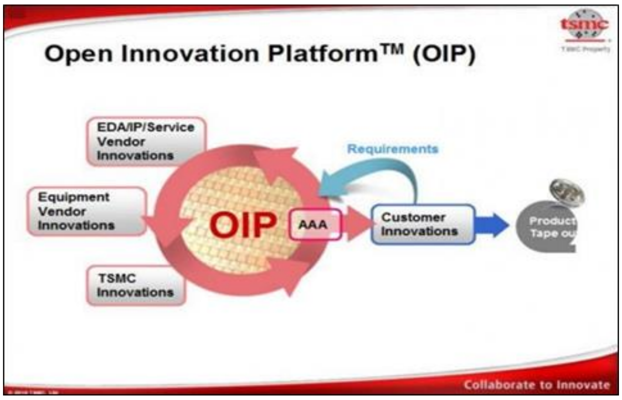

Fig.2 TSMC extends open innovation platform
By Daniel Nenni
Source:https://semiwiki.com/semiconductor-manufacturers/tsmc/462-tsmc-extends-open-innovation-platform/

2.2 Applications and development of smart manufacturing

At Hannover Messe 2011, the German government introduced the topic of Industry 4.0. As the global manufacturing industry enters a new era, many governments are actively pursuing the implementation of Industry 4.0 plans to reinvigorate their domestic manufacturing industry, and through this, maintain their competitive edge and global standing. To ride this wave of global industrial development, Taiwan government has planned for the implementation of Productivity 4.0, hoping to drive industries towards the R&D of smart machinery, Internet, big data analytics-based decision-making, logic systems of human-machine collaboration, etc. This new mindset shall improve manufacturing and operations, and help establish Taiwan's industries as major partners in the global smart manufacturing supply chain.

The early manufacturing industry often adopts reactive maintenance; however, in recent years, the industry's mindset has gradually shifted towards predictive maintenance, which analyzes the large amount of data generated in the manufacturing process to make further predictions. Manufacturing decision-making based on the analysis of these predictions can utilize the integration of various smart systems and implement the concept of smart manufacturing in actual applications within smart factories. Smart factories are built on the foundation of IoT-based manufacturing industry, systematically processing information of the manufacturing process through collection of big data and predictive analysis, in turn helping manufacturing processes achieve the goal of smart manufacturing (see Fig. 3).

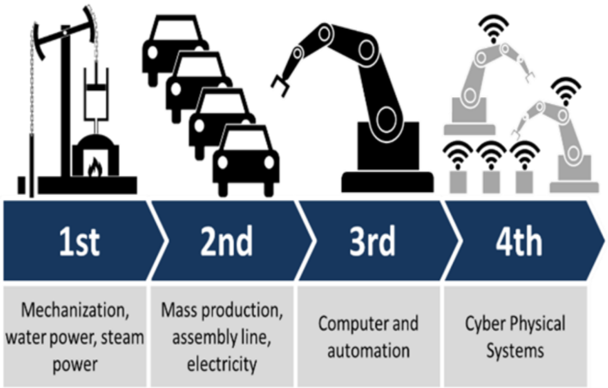

Fig.3 Industrial revolutions and future view by Christoph Roser Source: http://www.allaboutlean.com.

2.2.1 Data utilization in the semiconductor manufacturing industry

With the growing awareness towards Industry 4.0, the global manufacturing industry officially entered the age of big data and IoT, setting in motion the competition in advanced technology manufacturing, with the establishment of smart factories as an item actively pursued by the industry. Smart factories optimize resources to prevent unnecessary waste of resources. Smart transportation reduces the cost of material transportation and improves transportation efficiency. Smart grid technology optimizes power distribution and reduces power transmission loss. Smart products are realized through meeting the low-quantity, high-variety production needs for customized manufacturing, which is achieved by connecting IoT with manufacturing equipment. Smart logistics employs transparent logistics information and real-time monitoring to enhance logistics efficiency and help businesses resolve their own issues. In conclusion, smart factories can perform real-time diagnostics and monitoring on manufacturing processes via IoT applications and the collection and analysis of big data. This can help businesses resolve their own issues, effectively improving yield and enhancing the integration of production control (Kagermann, H., Helbig, J., Hellinger, A., & Wahlster, W., 2013).

In addition to the robust foundation upon which the development of the Taiwanese manufacturing industry was built, the industry also possesses advantages in the flexibility of supply chain cooperation and its experiences in manufacturing management. For example, the semiconductor manufacturing industry consists of upstream IC design companies, midstream IC manufacturers, which design and manufacture semi-finished goods. Semi-finished goods are then diced, packaged, and tested by the downstream companies before being sold to system vendors to produce system products. The comprehensive industrial cluster and professional division of labor have helped Taiwan stay ahead in the global competition of semiconductor manufacturers. How do we maintain this advantage in advanced technology? Smart manufacturing is probably the best answer to that question. Real-time decision-making is the heart of smart manufacturing, which is achieved through the integration of equipment engineering capability, manufacturing execution systems, manufacturing equipment, and automated material handling system.

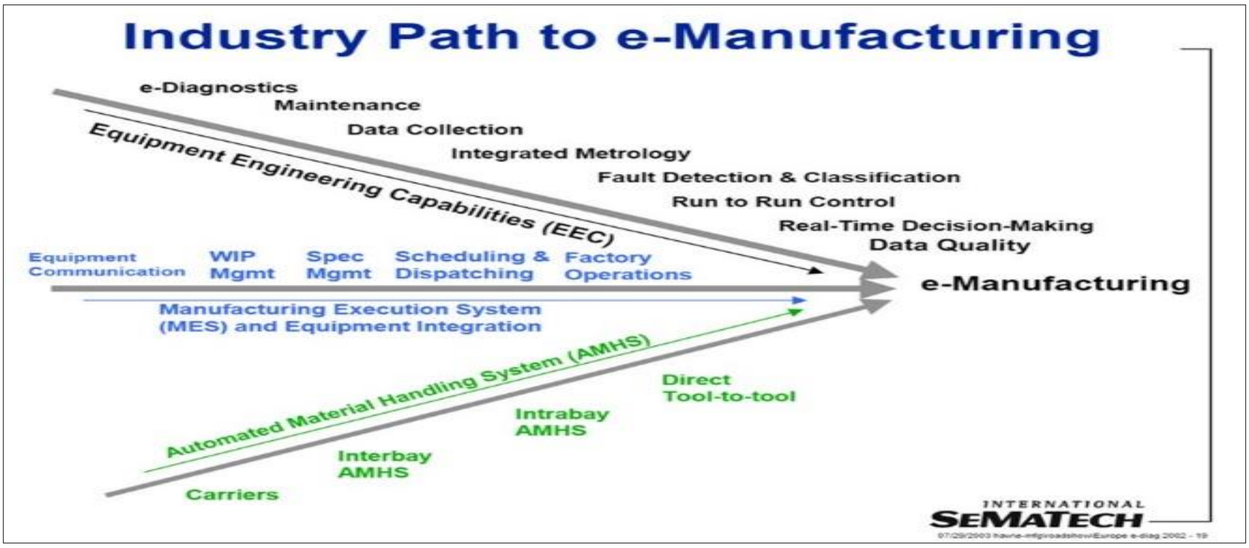

Fig.4 Electronics manufacturing roadmap
Source: International SEMATECH e-Diagnostics and EEC Guidance 2003

Equipment engineering capability is smart decision-making involving error prediction/classification and run-to-run control system. These are implemented through electronic diagnostic technology and integrated measurement via the collation and analysis of data concerning the equipment, personnel, process, and information of a manufacturing process (see Fig.4). The integration of manufacturing execution systems and manufacturing equipment includes communication between equipment and the management of manufactured goods and their specifications, which can facilitate factory operations and help with operational scheduling. This improves the flexibility of manufacturing systems and shortens reaction time. Automated material handling systems can further increase the flexibility and efficiency of transportation via the management of factory transportation carriers and the automated material handling system and direct transportation between and within areas.

2.2.2 IoT applications—increasing capacity and improving yield

In order for enterprises to strike a balance between cost and quality, the improvement of yield has become an important issue in production control. If an effective improvement of yield cannot be achieved, it can incur risks of under-supply or late delivery; business reputation is therefore an important criterion in choosing companies in the supply chain. With the globalization in supply chains, international collaboration and co-design have become major trends in the current high-tech industry. Increasing capacity and improving yield through the interconnection between system technologies are therefore important parts of advanced technology manufacturing and also a major element of trust in international enterprises. By implementing the idea of smart manufacturing, we shall observe a clear effect the Internet has on manufacturing. Through a mutual understanding of manufacturing equipment status and operational scheduling between enterprises, prompt reactions and general inventory management can be carried out between systems. Between the accelerated manufacturing and the reduction in manual inventory control, businesses can also reduce production defects. Enterprises should easily see quick results and increased profit after implementing smart manufacturing. In the long term, enterprises can also see a boost in corporate image and business reputation.

2.2.3 Smart energy management

Based on past experiences, equipment efficiency improvement and operational optimization can reduce energy consumption by 20 to 30 percent. In recent years, several enterprises have come under increasing pressure for energy conservation and carbon reduction from government policies, supply chains, and corporate social responsibility. The sound utilization of smart energy management technologies to achieve the virtuous cycle of effective energy distribution, low energy consumption, and equipment efficiency improvement is therefore an important objective sought by enterprises. The Industrial Technology Research Institute's Industrial, Science and Technology International Strategy Center defined the field of smart energy applications: power system monitoring (infrastructure end; power generation, transmission, conversion, and distribution systems) and environmental energy conservation/comfort level detection (user end; smart meter, smart plug, thermostat, smart gateway, smart lighting, smart smoke detector, smart home appliance, etc.). The most important technology that constitutes the components of all major application systems is a sensing technology capable of detecting environmental energy conditions at all times.

The core concept of power system monitoring is the use of electrical sensors placed throughout smart energy systems and power transmission, conversion, distribution, and consumption systems to issue timely warnings for detected electric power system anomalies and establish bi-directional interaction between electric utility companies (power distribution) and end-users (smart energy consumption). This can reduce electrical load and improve power consumption efficiency, so as to reach supply-demand equilibrium in electric power. For example, a supervisory control and data acquisition (SCADA) system is an actual application of an automated electrical distribution system on the power distribution/transmission end. A SCADA system monitors electrical anomalies in electrical network equipment via various built-in power monitoring sensors (current sensors, capacitive/inductive liquid level sensors, phase detectors, etc.) in transformers, so as to perform instant shutdown of equipment affected by tripped circuit breaker, power outage, or electrical issues.

3. Materials and methods

This study is a case study of a semiconductor manufacturer and is primarily centered around the process chilled water system on the fabrication end. An observation and analysis of the development and data collation of smart electric power sensor technology are performed by first describing the issues in system technologies, followed by a discussion of technical contradictions and using the inventive principles presented by the contradiction matrix to find the best technological application for sensor components. Finally, Failure Mode and Effects Analysis (FMEA) is utilized to analyze the process chilled water system for improvements in smart energy management, so as to improve efficiency and implement predictive maintenance. This chapter contains two sections, the first explains the problem-solving process of TRIZ, followed by a discussion of FMEA.

3.1 TRIZ

TRIZ is a tool of inventive problem-solving developed by Russian mechanical engineer Genrich Altshuller by analyzing hundreds of thousands of global patent literature and summarizing their problems and solutions. Beginning in 1946, he found systemic patterns behind the thinking and behavior of successful, innovative in-
34 ventors. In the development of this generalized problem-solving process methodology (see Fig.5), Altshuller clearly defined 39 basic engineering parameters and 40 inventive principles to solve contradictions between any two of the 39 parameters; the inventive principles are used for problem-solving, turning abstract principles into concrete solutions. The development of the TRIZ theory by Altshuller and his research team via a cross-disciplinary integration of principles and rules summarized the various regular patterns followed by technological development and evolution, and solved all kinds of technical and physical contradictions through innovative principles and rules.

Further investigation into the applications of the 40 inventive principles of TRIZ shows that within the concept of Industry 4.0, systemic improvement or changes can be approached through systematic thinking and system life cycle can be determined through equipment and internal components. This study classified the inventive principles into three categories: conceptual principles, technical principles, and material principles. The 40 inventive principles and their classification have a multi-faceted way (e.g., weight, shape, transmission mode, etc.) in approaching actual applications or design processes. By using the aforementioned classification, we can turn abstract problems into concrete ones and hope to find the best solutions for future designs that simultaneously solve systemic problems and improve operational efficiency.

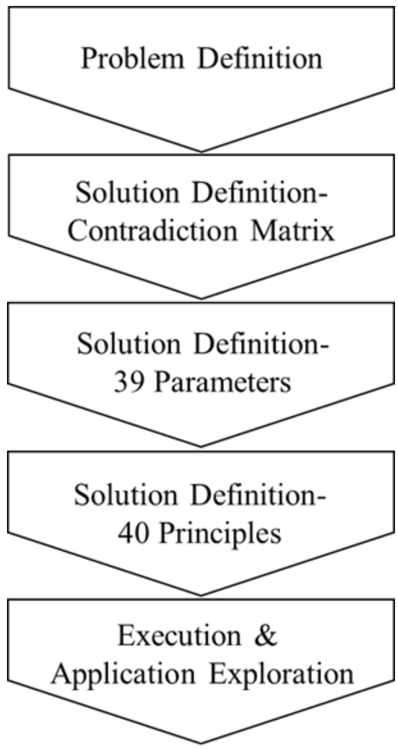

Fig.5 The problem solving process of TRIZ

3.2 Failure mode and effects analysis (FMEA)

FMEA is a design tool based on past experiences and failures. It can continuously verify and improve operating procedures in design, R&D, manufacturing, and assembly by performing careful analysis at the designing stage, detecting and eliminating factors of negative effects such as poor designs and human errors, leading to the goal of overall system optimization.

The FMEA methodology primarily uses system function reliability block diagrams and analysis tables to list potential failure modes of systems, products, or manufacturing processes. The occurrence of failures can be prevented by analyzing causes and potential effects, assessing priority for improvements, and drawing up effective improvement plans. After a formal implementation of FMEA into system analysis, the failures' effects on systems are evaluated. We can use the Risk Priority Number (RPN) to assess the risks and implement improvements based on the assessed priority. To calculate the RPN, we need to first evaluate the following:

(1) Severity:

The impacts on systems or personnel after the occurrence of the failure mode. This is evaluated based on the actual degree of the effects.

(2) Occurrence:

The likelihood of the failure mode occurring. This is usually determined based on the average number of occurrences in a fixed time period.

(3) Detection:

The likelihood of the detection of the failure cause in systems or manufacturing processes.

McDermott et al. put the factors of severity, occurrence, and detection on a scale ranging from 1 to 10 and defined the significance of each level of rating. However, due to the many restrictions imposed by practical considerations, the calculation of risk priority number (RPN) is: RPN = Severity (S) × Occurrence (O) × Detection (D).

4. Empirical analysis

Information integration on a smart energy management platform is highly correlated with the data monitoring of all systems. After diagnosing equipment status via data analytics, we can plan for the basis of predictive maintenance, thus reducing unnecessary hidden costs in manufacturing. In said platform, IoT is used for a customized energy management system that integrates technology based on end-to-end data collation. After technology integration, the system possesses the smart management capabilities of failure prediction, power management, auto-balancing control, and automated operation scheduling. Although this concept has already been implemented in the development of smart factories, energy management requires further improvement in equipment efficiency and data optimization. We hope to propose operational plans for overall efficiency enhancement in accordance with management decision-making in the future.

The subject of this case study is the process chilled water system of the semiconductor manufacturing industry; this system is provided for the manufacturing process and air conditioning operations. As seen in Fig. 6, the main water chiller unit has a higher energy consumption compared to the rest of the chilling equipment. The benefits of predictive maintenance can therefore be achieved by finding the operational energy consumption of the equipment in the system. After combining energy management principles with the analysis of smart electrical sensors using TRIZ and analyzing big data through the IoT transmission framework, we combine the result with the equipment characteristic curve and transmit it to the smart energy management platform for application analysis. This allows the platform to automatically convert energy consumption and have the operations set at the optimum energy-saving control point, thus achieving the goal of improved efficiency and predictive maintenance. The implementation of smart energy management platform can increase the industry's global competitiveness by combining innovative technologies with the energy management system of the existing Facility Monitor and Control System (FMCS), utilizing FMEA to reduce system risk, and planning for predictive management.

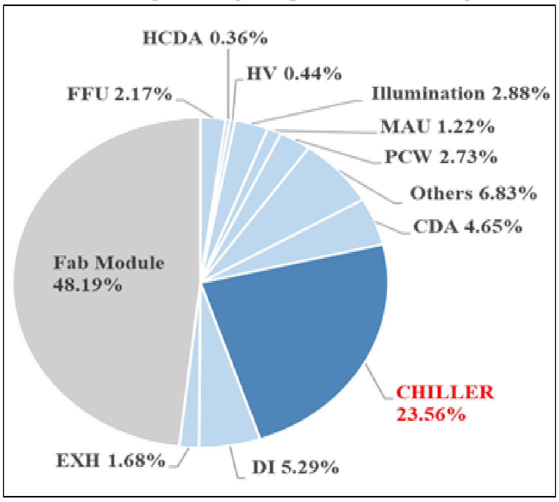

Fig.6 The proportion of electric power systems

4.1 Applications of process chilled water system

This is a process chilled water system of the semiconductor industry. Its function is to provide for the manufacturing process and air conditioning operations. As the main water chiller unit has a higher energy consumption, energy consumption data of the system is determined and transmitted via IoT to the smart energy management platform for further application analysis, so as to achieve the goal of improving efficiency and predictive maintenance. A process chilling system has a higher percentage in power consumption and consists of various smaller units, including power supply systems, control elements, and operational support equipment. Current measures employed are mostly regular maintenance, preventive maintenance, or predictive management. This section is a discussion of the use of smart electronic sensors and TRIZ problem-solving theory for innovative inventions, and the preventive evaluation and analysis of components capable of energy management.

(1) Operational equipment: Pumps

The pumps within a process chilling system are critical to its operation. Equipment overload damage (see Fig.7) caused by abnormal voltage, environmental issues, or poor insulation can lead to system shutdown if the components are not given preventive replacement/maintenance. Determination of equipment status is achieved by measuring the relevant voltage and current and performing predictive failure evaluation based on the regular maintenance cycle or component life cycle. However, technical difficulties concerning the actual use of certain components should be noted in advance.

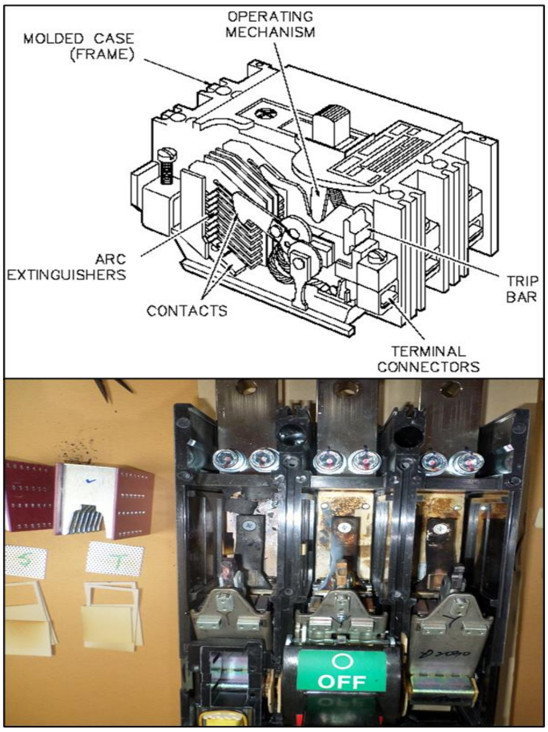

Fig.7 Abnormal pump equipment

(2) Control system: Electrical equipment switches

No-fuse breakers (NFBs) are the first line of preventive measures in all systems. The purpose of such breakers is to provide systems with overcurrent protection, overload protection, and short circuit protection. When in use, degradation of internal components is not easy to spot (see Fig. 8), which can lead to the breaker failing to cut power or trip in case of anomalies, which may in turn cause downstream equipment damage or fire, threatening personnel safety. Under regular safety standards, NFBs undergo service life evaluation; and the service life of internal mechanical and electronic components are positively correlated. Currently, preventive maintenance and replacement can only be performed on equipment with anomalies in energy use by using infrared thermal imaging to measure the thermal radiation generated by components.

(3) Control system: Multi-function power meter

The semiconductor manufacturing industry has a complicated model in power supply and demand. For major energy consumers in the industry, effective energy management can only be achieved by controlling manufacturing or operational power consumption. Digital panel meters are used to measure the voltage, current, power, frequency, and demand of a power circuit, and are therefore important equipment in industrial energy management. The regular data transmission mode establishes physical wiring layouts and completes data output via RS-485 standard serial communication protocol, achieving anomaly detection and management on the remote monitoring platform. However, effective energy control cannot be achieved if the transmission fails due to issues with the physical wiring (see Fig. 9), if there are power detection issues, or if the meter has internal component damage. Using the TRIZ problem-solving theory for innovative inventions, we can move towards the development of meters or related sensors that utilize wireless communication technology, so as to implement improvements in areas where physical wiring are difficult to place or in meters with power anomalies.

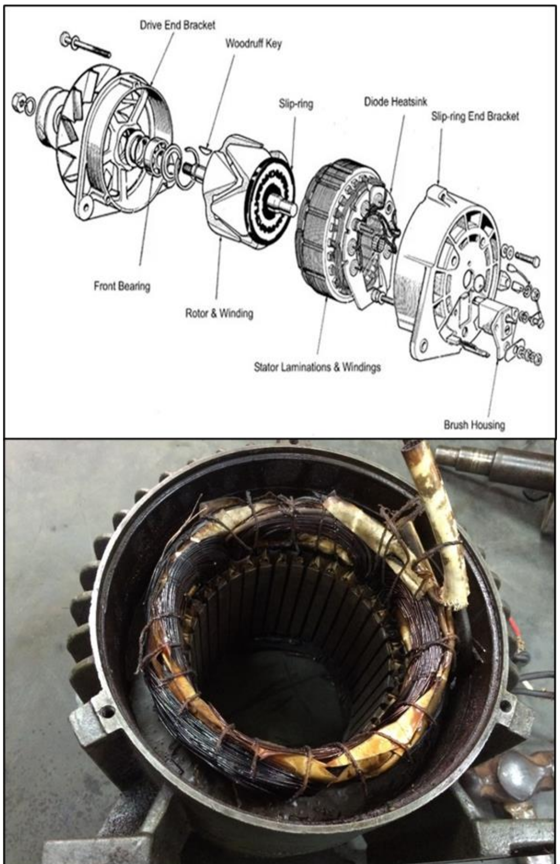

Fig.8 Abnormal switch equipment

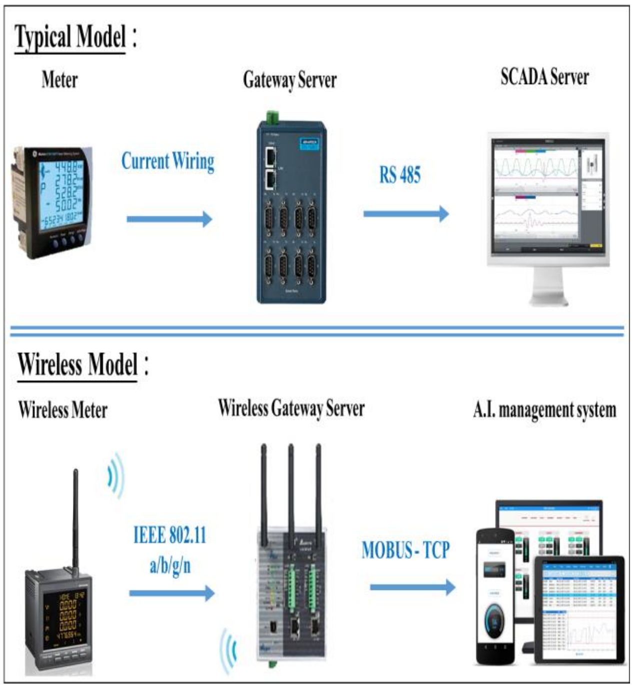

Fig.9 Energy management and wireless data transmission

(4) Uninterruptible power supply (UPS)

The primary function of a UPS is to provide the load with the stored energy in its battery when it detects voltage anomaly or power outage in the mains (Taipower), providing an uninterruptible power supply until power returns. Various control elements in the process chilling system require uninterruptible power in order to power the operations of control elements during system anomalies. UPS operates in standby mode over long periods of time and therefore require better ventilation to control the temperature for its internal power conversion and energy storage units. The internal fans are controlled via signals based on the monitored temperature; overheating inside equipment can lead to degradation of electronic components (see Fig. 10). The operational status of the fans is currently determined through system maintenance/replacement or through the experience of inspection-performing personnel. Using the TRIZ problem-solving theory for innovative inventions, we can develop sensors capable of monitoring the operational status of fans, collating their data, and performing predictive failure evaluation before any occurrence of fan failure or other anomalies. An equipment health inspection system is established on the smart energy management platform to perform decision-making for failure prediction and diagnosis.

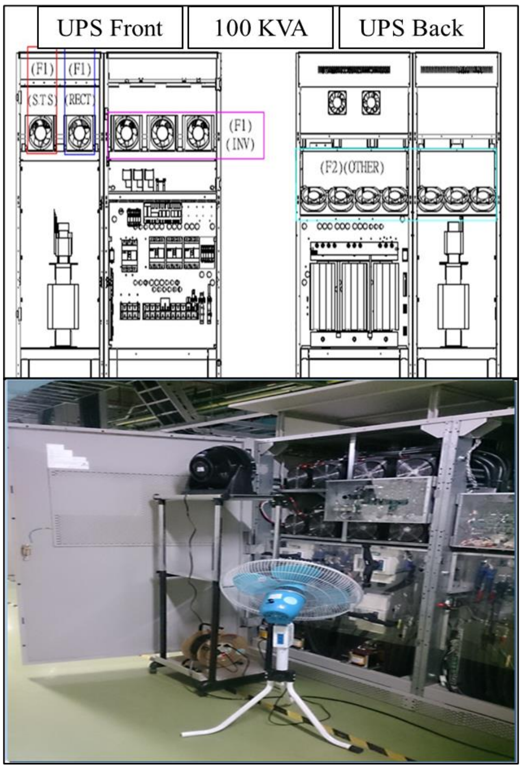

Fig.10 Abnormal UPS equipment

4.2 TRIZ analysis of the technological development in smart electrical sensors

In this age of rapid technological development, stable power supply and electrical accident prevention are vital to production control. The development of related smart sensors and the establishment of smart grids ensure equilibrium in power distribution, which is the basis for government implementation of energy management and data collation; it is also an energy policy objective for many countries around the world. Applications of smart grids and related sensing technologies entail the implementation of said technologies in manufacturing processes or electrical equipment. By integration the electrical sensors in various electrical equipment and integrating them with the remote power monitoring system, we can detect overload or equipment anomalies in the overall system. In the case of anomalies, the remote monitoring system can transmit control signals to control equipment operation, which in turn ensures operational safety, prevents accidents, and achieves energy control.

4.2.1 Description of system technical problems

(1) Miniaturized electronic design

In this age of smart energy grid development, stable power supply and safety need to be major considerations for overall systems. For this reason, suitable current transformers should be used to measure electric current. A traditional current transformer (TCT) operates by measuring the current in the primary winding induced by the flux generated in the internal iron core. In the case of electrical system failure, instantaneous non-linear current can occur with a power surge, which threatens the safety of the electrical system. Due to their large size, TCTs can affect the planning of manufacturing facilities and their layouts, and require time and labor costs for their regular maintenance. Therefore, improving on the size of TCTs is the primary goal (see Fig. 11) in practical application. However, the size reduction in current transformers will affect their precision, resulting in various issues, including error when performing measurement on components.

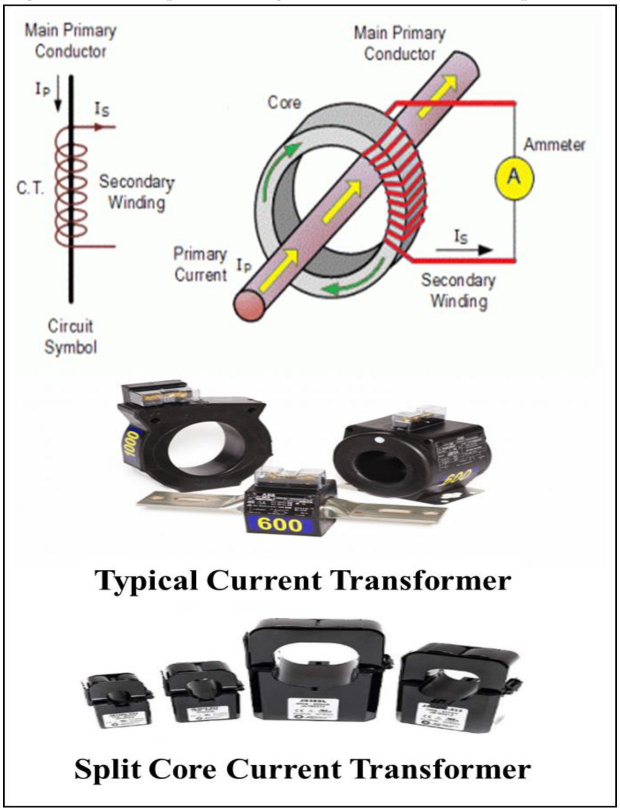

Fig.11 Current transformer technical principle

(2) Wireless inductive charging

A power supply is another point of consideration for improvements on smart sensors with wireless transmission capability. Current sensors placed in power grids require the design of power supply in accordance with their needs using the TRIZ theory for innovative thinking. The design of a wireless charging power source is present in many inventions; the convenience and safety of its primary design make it suitable for applying the TRIZ problem-solving theory for innovative inventions (see Fig.12). By combining wireless charging with current sensors, we can create smarter sensors.

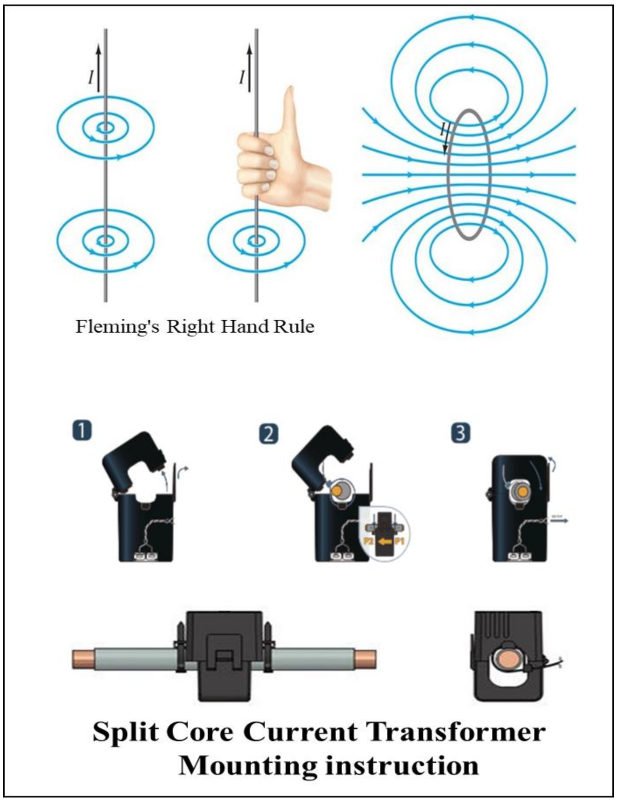

Fig.12 Magnetic field technical principle

4.2.2 Applications of TRIZ contradiction matrix

(1) Miniaturized electronic design

- Improving technical parameter: 12. Shape

"Shape" is the functionally necessary internal and external shape/contour of systems and its elements. For the semiconductor manufacturing industry, which seeks high quality and yield, the process planning, regular maintenance, and breakdown maintenance of manufacturing facilities are heavily considered when designing their layouts. Small-dimension designs free up more space and allow flexible planning in assembly lines. Improvements in time and efficiency can also be seen in the installation, transportation, replacement, and maintenance of equipment.

- Worsening technical parameter: 28. Measurement accuracy

"Measurement accuracy" is the level of deviation or error in measurement—i.e., the closeness of the measured value to the actual value. The electronic design of system components can improve data transmission capability and effectively improve the accuracy and stability of measured data. Miniaturized design enhances safety in installation and operation.

The technical parameters 12 and 28 correspond to principles 28, 32, and 1 of the forty inventive principles presented in the contradiction matrix. By using Principle

28: mechanics substitution—use electric, magnetic and electromagnetic fields to interact with the object—we acquired the result. As electronic components continue the trend of thin, light, and miniaturized design, corrective analysis is performed on the fundamental electrical and mechanical structure and mechanical components, so as to improve their shapes and plan for integrated design and optimizing measurement accuracy, thus achieving the goal of miniaturized electronic design. In addition to size and measurement accuracy issues, the analysis of wire charging applications in TCTs is as follows:

(2) Wireless inductive charging

- Improving technical parameter: 38. Extent of automation

The technical parameter "Extent of automation" is the extent to which a system or object performs its functions without human interface. Based on the changes in data management and operation mode, energy consumption can be reduced in peripheral devices by reducing electronic sensors or putting them on standby.

- Worsening technical parameter: 23. Loss of substance

The technical parameter "Loss of substance" is the partial or complete loss/waste incurred on a system. Energy consumption of data transmission often uses external power supply as the main power source. The long-term continuous operations of the system can shorten component service life. Additionally, the greater the power dissipation, the greater the power demand.

The technical parameters 38 and 23 correspond to principles 35, 10, and 18 of the forty inventive principles presented in the contradiction matrix. By using Principle 18: mechanical vibration—using an object's resonant frequency or using combined ultrasonic and electromagnetic field oscillations—we acquired the result. The accompanying planning for component power supply is another developmental focus of miniaturized electronic component designs. As the original plan for power supply may require revamp, energy allocation and demand are technical hurdles that need to be overcome. Through the combination of miniaturized electronic design and electromagnetic energy exchange, wireless charging technology can deliver electrical energy to smart electrical sensors via magnetic induction or resonance, achieving the goal of improving wireless power technology applications.

4.3 TRIZ analysis of the data collation in smart electrical sensors

The communication framework of smart manufacturing plants achieves the goal of smart management by enhancing control over the communication equipment, network environment, and cloud management of automation equipment. Through the use of IoT real-time detection capability, long-term monitoring, and regular inspection of equipment status, the framework can report anomalies when the equipment exceeds the alarm threshold value. This gives management control over equipment power and environmental variables via the energy management system. The implementation of IoT in energy management provides manufacturing processes with an advantage. As there is a diverse range of electrical equipment in manufacturing plants, anomalies could only be detected through regular inspection and maintenance. In order to provide management with the capabilities of remote management, monitoring & diagnostics, and energy consumption awareness, IoT-connected wireless sensors are combined with cloud data application (see Fig.13). This is critical to the management model of smart factory applications.

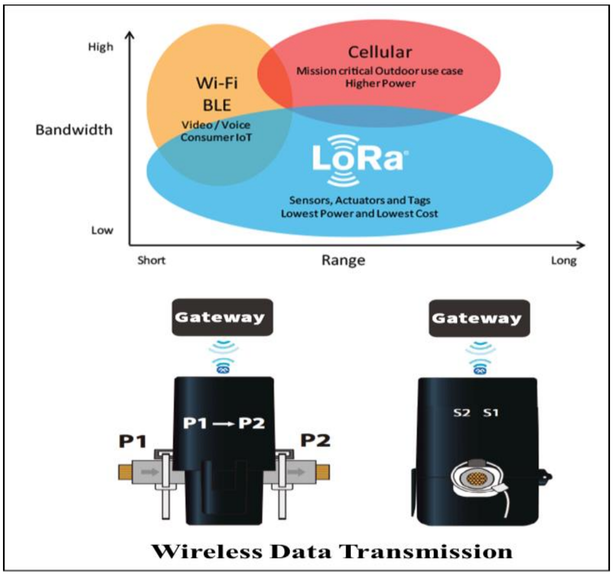

Fig.13 Range vs. bandwidth for IoT connectivity technologies

4.3.1 Description of system technical problems

(1) Cloud data collation—wireless transmission system

In the communication framework of a traditional manufacturing plant, electrical equipment, detection functionality, and related sensor applications all rely on wired communication. However, the number of sensors installed has increased with the growing demand for equipment monitoring, resulting in signal interference and connection issues between components, which in turn affect the collation, storage, and immediacy of data. Furthermore, with the increasing number of physical wiring due to the growing demand for connection, these plants now face mounting installation costs incurred by the need for long-distance communication and the shortage of equipment connection points.

4.3.2 Applications of TRIZ contradiction matrix

- Improving technical parameter: 27. Reliability

The technical parameter "Reliability" is a system's ability to perform its intended functions in predictable ways and conditions. Through the use of developed network protocol systems, we separated functionality and applications, turning it into a subnetwork system. This helps alleviate the connectivity issues between different systems and improves the reliability of data collation.

- Worsening technical parameter: 26. Quantity of substance

The technical parameter "Quantity of substance" is the number or amount of a system's materials, substances, parts, locations, or subsystems. Since a large number of network devices can cause signal interference, the initial network framework must be separated into various sub-networks.

The technical parameters 26 and 27 correspond to principles 21, 28, and 40 of the forty inventive principles presented in the contradiction matrix. By using Principle 21: Skipping—enhancing transmission speed and efficiency and shortening transmission time—we acquired the result. The number of equipment sensors is increasing with the implementation of smart manufacturing. Because of the varying development of sensors in different equipment applications, the integration difficulty of physical wirings due to the separation of independent systems, and the lack of reserved spots, the functionalities of wireless transmission technology in the smart management framework are separated, using long-distance communication to perform wireless data collation.

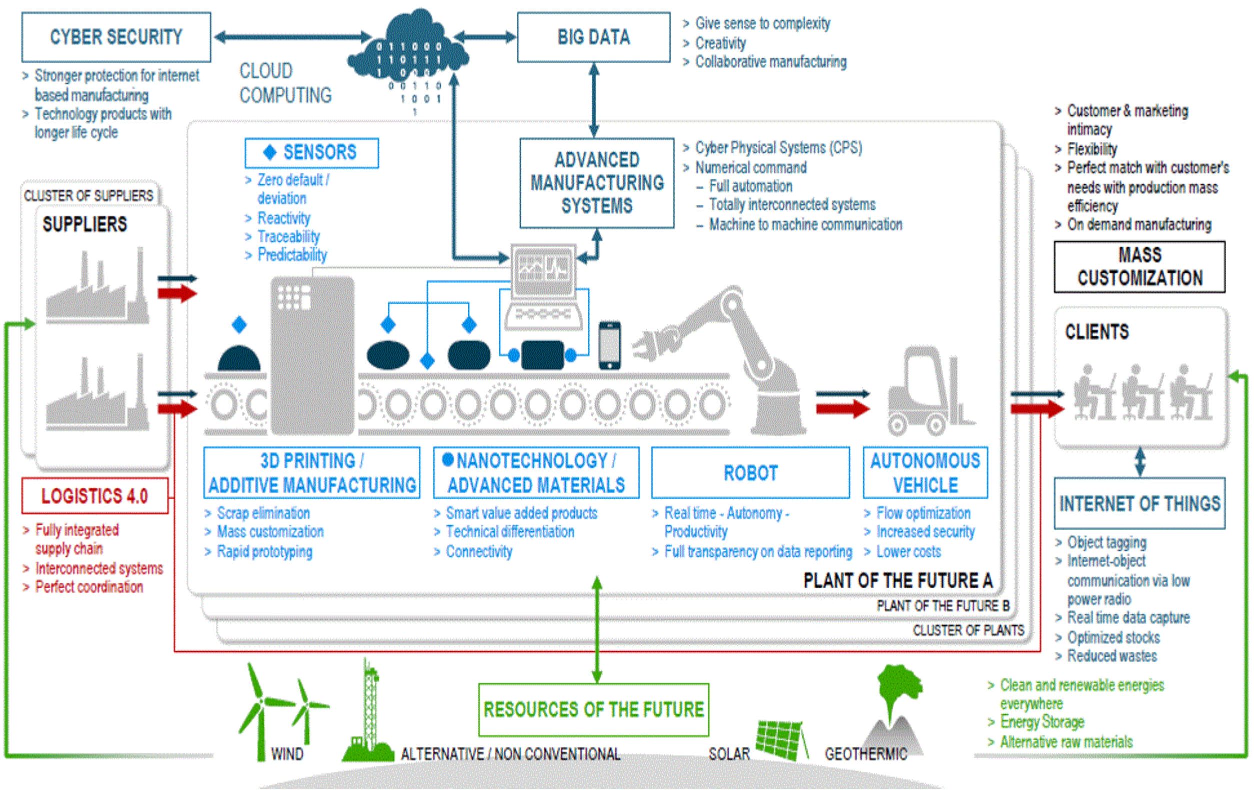

Fig.14 The framework of industry 4.0 ecosystem Source: Berger, R. (2015)

To summarize the preceding analyses, an electronic sensor for electric power has all the functionalities of a traditional electric power sensor. However, besides the differences in operating principle and structure, an electronic sensor for electric power also alleviates issues of dimension, weight, and cost, while fulfilling the demand for high-precision measurement and system protection. The new form of energy transmission technology also improves on certain flaws concerning safety, including the elimination of the need to plug and unplug cables, thus avoiding electrical contact failure. New electric power sensors based on the aforementioned technologies can enhance their sensing capabilities and perform wireless transmission of data.

By using wireless charging to reduce cost, implementing electric power monitoring sensors in energy management, we can establish customized systems that combine energy-saving management and energy safety (see Fig.14). We can also incorporate sensors of different applications to move towards a form of manufacturing that integrates multiple functionalities.

4.4 FMEA evaluation of application and management

The aforementioned FMEA analysis table was used in this study to evaluate whether applied innovative technologies can overcome potential critical failure modes in the system, thus reducing or eliminating their effect on the system. The RPN—calculated from severity, occurrence, and detection—is used to determine the improvement's effect on the system and the level of technological implementation, so as to draw up improvement plans or related control measures (See Table 1). Through the informatization of big data and the implementation of new technologies in the smart energy management platform, we can improve on the existing energy management model and benefit from predictive maintenance.

Table 1. The FMEA process of cooling water

Item	Original RPN	Measures	Improved RPN
Pump	256	1. Review of regular replacement and maintenance of equipment components. 2. Installation of additional smart sensors to measure related data and transmit data to the smart energy management platform via wireless transmission.	32
Electrical equipment switch	144	1. Regular equipment maintenance 2. Evaluate the design for smart sensors to automatically collect related data and transmit data to the smart energy management platform, so as to control load transfer.	48
Digital panel meter	192	Review of equipment's smart functionalities (e.g., wireless transmission), collection of related data, and transmission of data to the smart energy management platform.	48
UPS	320	Plan for the implementation of equipment inspection management functionality, which can determine the equipment life cycle for the smart energy management platform to perform predictive management.	64

We utilized FMEA to analyze the improvement in risk priority numbers (see Fig.15). Traditional energy management generally uses limited unidirectional transmission, which means that data is transmitted to the management platform via internal networks. However, power distribution data can often be difficult to monitor due to various engineering factors such as wiring layout or interference, resulting in losses and making it difficult to establish a suitable energy management policy. In comparison, smart energy management implemented with smart electrical sensors provides effective control of equipment data via IoT, achieving diverse integration and management between management platforms. This highly efficient interaction can facilitate the functionalities of maintenance/expansion and real-time monitoring in the energy management system. Data analysis performed by the smart energy management platform can be further used to development new forms of IoT and sensors, improving efficiency and management.

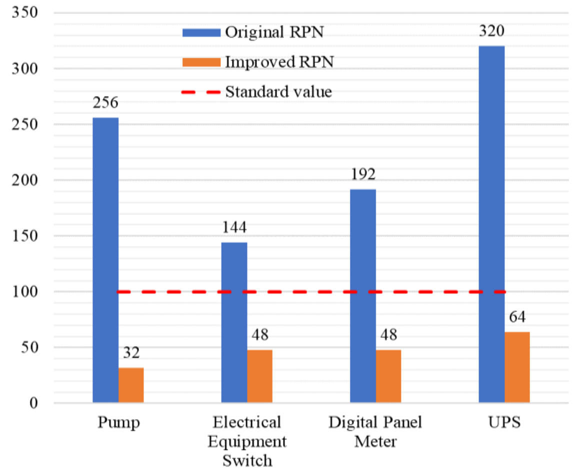

Fig.15 The bar chart of RPN

5. Conclusion

The implementation of Industry 4.0 in enterprises fulfilled the manufacturing model of smart manufacturing systems. This includes smart manufacturing, smart equipment, smart energy management, and smart manufacturing supply management. This study approaches the case study of smart energy management in the semiconductor industry from the data collation aspect. The technological integration of network transmission, data collation, and equipment operational status help businesses determine potential equipment anomalies within an acceptable time period and propose predictive management. This allows for enhanced manufacturing efficiency and flexibility while avoiding late delivery. In conclusion:

(1) Complete optimization of energy efficiency by achieving real-time monitoring and data management via smart equipment

In the past, electrical equipment management generally utilized limited unidirectional transmission, which uses internal networks to transmit electric power data to the management platform. However, power distribution data can often be difficult to monitor due to various engineering factors such as wiring layout or interference, resulting in losses. Through the implementation of smart electric power sensors and customized design in accordance with manufacturing processes, effective data control of equipment can be achieved via IoT. This improves energy efficiency, reduces operational cost, and achieves diverse integration and management between management platforms, greatly benefiting commercial smart energy management strategies.

(2) Complete optimization of manufacturing efficiency by utilizing real-time information integration to achieve predictive management

With the technological breakthrough in sensors, the combination of smart energy management systems and electric power sensors has replaced the management model of the past, which is limited to local monitoring, manual inspection, and incompatible electronic systems. Improvement in the automation model's real-time digital information concerning maintenance management, data collation, predictive maintenance, and environmental monitoring can help determine potential operational risks of equipment, including energy consumption anomalies and risks in predictive maintenance planning. This reduces the risks and losses incurred by failure and shutdown, and can further facilitate bidirectional analysis of other systems and equipment information. Improvement of the overall operational effectiveness of manufacturing processes can be achieved by improving unit inspection system, unifying standard procedures, and progressively establishing database systems, thus achieving the goal of procedure optimization.

(3) Reach optimal operation by helping business resource allocation via advanced smart energy management

In the case of manufacturing process anomalies or product complaints, a reverse data lookup can be performed on the data collected via the smart energy management platform. This allows businesses to conduct analysis over the 5M1E factors (man, machine, material, method, measurement, environment) and implement control measures accordingly, thus improving energy efficiency, reducing operating costs, and implementing green supply chain management.

As the establishment of the smart manufacturing framework completes, corporate departments related to the planning of management shall begin to play bigger roles within the enterprise. With technological advances come improvements in engineering technologies, and management shall also face their corresponding problems, including: (1) Is the new business model introduced for overall operations or management decisions? (2) How to further development in smart manufacturing? (3) Can modular manufacturing systems be implemented? (4) If co-design is required, can alliances be formed with clients, contract service providers, or competitors to enhance each other's technological capacities? Future development of smart applications shall focus on interactive applications combining artificial intelligence and virtual reality. With computational thinking moving from mobile-first to artificial intelligence, smart applications utilizing deep learning has begun to emerge in various high-tech industries. As men become used to living technologies, back-end data analytics and computation are merely the results of deep learning; decision-making, comprehension, and critical thinking are still performed by management. As we ponder over the fast-evolving future of human-computer technologies, the comprehension of the analytic judgment, regulation enforcement, and moral philosophy concerning smart applications is questions that need further discussion on another level.

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Creative Engineering Design of Automotive Brake in Rainy Days Using TRIZ

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Abstract

This study resolves the brake problems of general automobiles in rainy days by using Theory of Inventive Problem Solving (TRIZ). In the process of the study, we first explored the use of commercially available motorcycles. Through the observation, it is found that the brake of automobiles generally consists of two braking systems. Also, the three most common compositions are double drum brake, front-disc and rear-drum brake, and double disc brake. The targeted brake in this paper is the new type of disc braking system. Rainy days easily cause automotive brake failure and thus skidding. This paper carried out function analysis of the safety of the automotive braking system, and meanwhile used 39 Engineering Parameters and 40 Invention Principles and 76 Standard Solutions for a series of discussions. Eventually, such design as modifying discs was used to stabilize and enhance the braking capacity to ensure the automotive safety under different circumstances and increase the stability in running.

Keywords: TRIZ, Automobiles, Braking system, Creative engineering design

利用 TRIZ 發明性問題解決理論進行雨天機車煞車之創意性工程設計

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摘要

本研究利用發明性問題解決理論(Theory of Inventive Problem Solving)之工具，來解決一般機車在雨天之煞車問題。探討過程中首先查察市售摩托車之使用方式與操作習慣，經觀察後發現機車在剎車作之設計部分，一般是由二種煞車系統所構成，同時其組成方式有雙鼓煞、前碟後鼓煞及雙碟煞等三種，最常被實際使用。本文主要致力於較新型的碟煞系統為研究重點，並針對雨天容易使機車煞車失靈造成打滑的因素和解決方法進行創新設計，同時輔以探究煞車系統，進行元件分析(Function analysis)以強化其安全性，以及使用 39 工程參數與 40 發明原則、76 種標準解等 TRIZ 部分工具，進行系統性的創新設計探討。探究結果顯示，採用修改碟片特性功能等之創新設計，將有助於作為穩定與提升制動能力，並可以確保在不同環境(雨天)情況下，完善行車的安全性。

*關鍵詞：*系統性創新、機車、煞車系統、創意性工程設計、發明性問題解決理論(TRIZ)

發明性問題解決理論簡介

當工業進入 20 世紀後，隨著人類文明的進步，人們一再改良與創新出更新穎的科技，以提昇人類生活的品質，使生活更為舒適且便利的新發明、新科技呈現指數的向上成長，但並非每樣創意在被構思時都是有明確用途的。前蘇聯發明家 G. Altshuller（1926 – 1998），經由整理幾十萬件的發明專利並歸納研發出對於問題的解決方法及工具，提出以準解最為解答各領域的問題，當將來各領域發生相似的問題時，其解決的方法也應該類似而有跡可循(Altshuller, G., Al′tov, G., & Altov, H, 1996)。只要好好歸納這些問題及解決辦法，做好分類，即可按圖索驥，套公式解決問題，便大功告成了。參考相關創意性工程設計相關論文著作(Altshuller, G., Al′tov, G., & Altov, H, 1996；宋明弘，2012；許棟樑等人，2016；翁永進，2016)，可以發現 TRIZ 是個有效作為問題解決之工具，並用來幫助思考，例如：工業產品與產量改良進化以及產品開發組合用用上的創新設計(Lan, W. C., & Sheu, D. D, 2015；Liu, T. L., & Chen, J. W, 2017)，可以經由 TRIZ 提出多種產品創新組合新方案；協同產品設計過程中的衝突方案與技術專利佈署上的相關研究(Liu, T. L, 2012；Liu, T. L., & Kuo, S. T, 2011)，TRIZ 工具也相當有助益；此外，對於商業產品有時亦得重新給予新設計(Sheu, D. D., & Hou, C. T, 2011；Sheu, D. D., & Hou, C. T, 2015；Sheu, D. D., & Tsai, M. H, 2015)，以及考慮使用者行為的感知應設等功能，TRIZ 亦發揮得相當完善；另外，簡約設計上 TIRZ 亦扮演重要角色，可優化產品並在低成本高價值上發揮其重要功能，例如應用在電動汽車上的馬達冷卻系統等在 TRIZ 操作後，有效減少零件，並達到更優異的冷卻效率(Sheu, D. D., & Ho, C. L, 2016；Sheu, D, 2015；Weng, Y, 2018；)。將 TRIZ 比喻為一台汽車時，發明家就是駕駛者，而汽車所行使的方向、速度就要仰賴每個人不同的專業知識及經驗了。所以最終還是要靠人來完成工作，這套理論只是幫助你更快找到解答的方法，以下本研究之創意性工程設計一詞，主是因為使用 TRIZ 方法進行工程設計與改良使得工程設計創新而稱之。

2.下雨天機摩托車之煞車安全性問題與現況分析

本研究為針對雨天對於市售摩托車之煞車系統安全性影響設計探討。以普通重型摩托車而言，經觀察發現機車由二種煞車系統構成，組成方式有雙鼓煞、前碟後鼓煞及雙碟煞等，本文鎖定之煞車為較新型的碟煞系統。報導指出雨天容易使機車煞車失靈，造成打滑車禍等憾事發生，而在這之中，人為因素也佔了極大之比例，許多駕駛在騎乘機車時忽略了雨天會使煞車系統制動力明顯降低而判斷失準，以致煞車不及。本研究利用 TRIZ 不同創意方法，進行煞車設計以提供用人們更安全的騎乘工具。

關於剎車相關制動力研究中(林金財，2001；王鵬竣，2014)，總結煞車問題，大致推導出造成問題之相關可能原因如下：駕駛者在一般天氣及路況下騎乘時，已習慣原本之煞車強度及煞車距離，於雨天行駛時，在煞車系統都被沾濕的情況下，煞車強度大幅降低，煞車距離被大幅拉長，但騎乘者仍預期原本之煞車距離，造成急扣、急煞等不當操作，導致車輛打滑等意外發生。在此，本文將針對煞車系統在不同環境但同一煞車模式下，以發明問題解決理論工具進行安全性創意工程設計，最後再進行整合分析。

3.雨天機車煞車安全性問題與現況分析

3.1 元件分析(Function analysis)設計探討

本部分首先針對摩托車在晴天與雨天剎車進行初步子系統(Sub-system)、系統(System)與超系統(Super system)分類其危險問題產生的情況之相關性。本文以圖 1 簡易示意圖作為表現。本研究將圖中元件分類為系統:機車；子系統:輪胎、碟盤、卡鉗；超系統:障礙物、雨水，如圖 2 所示。

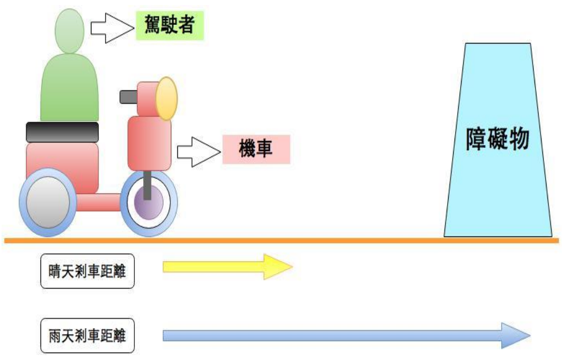

圖 1.天氣影響煞車距離長度問題之簡易示意圖(註：黃色箭頭與藍色箭頭之長度差距為駕駛者會撞到障礙物的危險範圍)

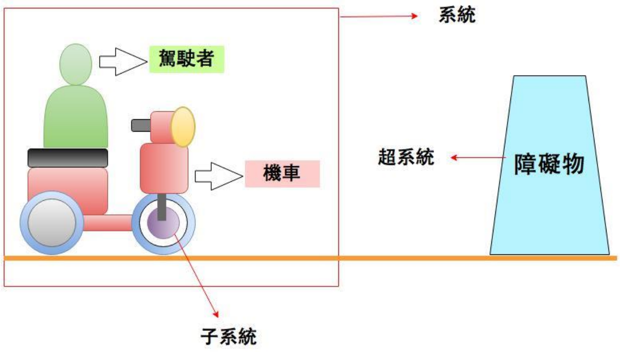

圖 2.騎士扣煞車時的情況之系統、子系統與超系統分類

本文將系統各部元件(子系統)有相關性的部分進行探討，如表 1 所示。其中，將其有相互作用(Internation relation)關係的以正號(+)表示；沒有相互作用關係(No-internation relation)的以負號(--)表示，若會造成害處(Harmful relation)的則以(H)表示。

表 1 系統各部元件作用情況分析(元件分析)

FA	輪胎	碟盤	卡鉗	雨水
輪胎		+	-	H
碟盤	+		+	H
卡鉗	-	+		+
雨水	H	H	+	

圖 3.為探討之碟煞之煞車元件示意圖，其煞車力道 = 夾持力 x 力臂 (碟盤尺吋)，而夾持力來自煞車卡鉗(來令片)與碟盤之間的摩擦力。

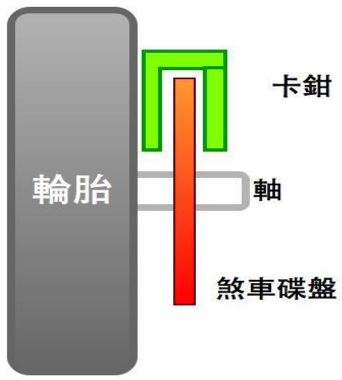

圖 3.機車煞車元件之分布圖，碟煞在煞車時，卡鉗夾住煞車碟片造成摩擦力

圖 4.為探討個別元件之不足作用、有效作用及有害作用等之圖示分析。我們可以歸納出幾個煞車問題因素：當駕駛者看到前方出現障礙物時，會依照原有之駕駛習慣以相同之力道扣下煞車，代表卡

鉗夾持碟盤的力道是不變的，本文在不考慮輪胎與地面磨擦力的情況下，當碟盤沾到水時會讓表面之摩擦係數大幅下降，進而影響整個煞車系統的制動力。換言之，車輪在轉動時突然要求煞車，其剎車對車輪的摩擦力就是所謂的制動力，這種力一般是利用摩擦力將運動的機構快速停住。

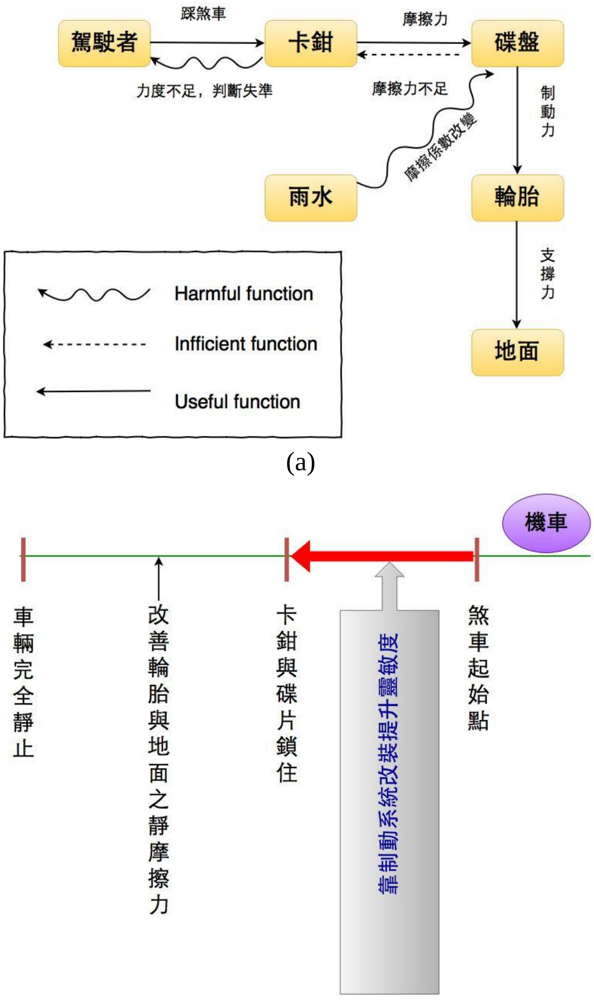

圖 4 剎車(a)圖示分析(b)制動力動作流程圖

另外，當駕駛發現機車煞車靈敏度不如預期時，會因緊張而有重扣煞車等不當操作，造成輪胎打滑等危險情況發生。因此，本文以輪胎不做任何設計改變之情況下，僅以改善制動力為出發點做相關之簡約設計(Trimmimg)。

3.2 利用 39 工程參數和 40 發明原則對改善制動系統進行探討

本部分主要以使用 39 工程參數與 40 發明原則進行煞車系統在雨天時的制動能力，該方法經常使用於工程方面，在面對不知如何解決的問題時，先試著用最直觀之解決方法處理，然而最直觀的方式必然會產生新問題發生，當我們將其目標、解決方式、產生之新問題一一列出(表 2)，使用矛盾矩陣(Conteradiction Matrix)並經常依據其所給予其產生原則成為新創意之方向。

表2. 歸納出目標、方法、新問題

目標	增加雨天煞車效率
方法	使用塑膠外殼包覆，不讓雨水沾濕煞車碟片。
新問題	碟片無法散熱。

經由初步考量後，由於煞車系統經過專業設計，因此改良機車之制動能力以易拆裝原件為優先設計之重點依據，將著重於改善不同天氣行駛機車時，制動能力差距的幅度可以降到最低，而非單純的增加制動能力。以此構想，研究者判斷當去除雨水這項因素時，基本制動能力就不會有任何差距了，所以初始概念是用塑膠外殼包覆住整個煞車碟片和卡鉗(圖 5)，如此就可解決先前問題，但煞車系統在運作時，因摩擦會產生高溫，用塑膠外殼將其包覆住，會使其溫度過高無法散熱造成來令片、碟盤熱衰竭，煞車效率下降，系統壽命減低等新問題。

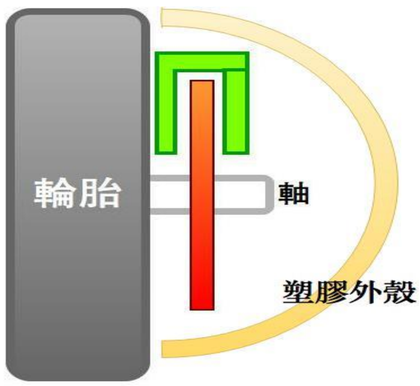

圖 5. 使用塑膠外殼包覆煞車

因此，本研究進行可能的發明原則判斷，設定欲改善參數設定如下：物體外在有害因素(30)、裝置的形狀(12)；惡化參數設定為：裝置溫度(17)、機構工作效率(21)進行矛盾矩陣查羅列並應用，如表 3 所示。

表 3. 矛盾矩陣表

惡化 / 改善	21.機構工作效率	17.裝置溫度
30.物體外在有害因素	19,22,31,2	22, 33, 35, 2
	19.週期性的動作 - Periodic Action 22.將有害變成有益 - Convert Harm into Benefit; Blessing in Disguise, Turn Lemons into Lemonade 31.多孔性材料 -Porous materials 2.分割–Taking out	22.將有害變成有益 - Convert Harm into Benefit; Blessing in Disguise, Turn Lemons into Lemonade 33.均質性 -Homogenrity 35. 參數改變/屬性轉換-Parameter Changes; Transformation of Properties, Transformation of Physical state of an Object 2.分割– Taking out
12.裝置的形狀	4,6,2	22,14,19,32
	4.不對稱性 -Asymmetry 6.通用性- Universality 2.分割– Taking out	22.將有害變成有益 - Convert Harm into Benefit; Blessing in Disguise, Turn Lemons into Lemonade 14.球形化- Spheroidality-Cushioning 19.週期性的動作- Periodic Action 32.改變顏色- Color Changes

經由矛盾矩陣後，可進行改良之發明原則有最高重複性及可使用性的方法可縮減為兩樣：22.有害變有益、2.分割。經由力學及設計探討下，當碟盤在工作時，其摩擦力產生之工作溫度平均為百度上下而摩托車下坡路段連續煞車持續4~5分鐘，碟盤溫度可飆高破二百多度以上高溫，故保持空氣流通及散熱這一環為煞車系統中舉足輕重的關鍵，而矩陣所提供之原則也給予部分改良靈感。

原則2：分割：從一物體中提煉、移除、分離出不想要(有害)的部分或屬性。雨水所改變摩擦係數是本文所致力要移除的一項負面因素，故得知，設計構想朝向排水性能發展。

原則22：將有害因子變有益：轉變有害的物體或作用以獲得正面的效果。雖然雨水會增加卡鉗夾持碟盤產生阻力之不確定性，但水與空氣所予的散熱降溫卻是對碟盤有好處的。

結合此二發明原則，我們可得出初步理念就是針對碟盤的排水能力進行改善，則可解決散熱和制動力不足的問題。目前做法是先將碟盤上添置數條到數十條線的溝槽，當卡鉗在夾持時會將水滴押進溝槽中，藉此來排出水來。至於進一步討論，往後將運用新方法找尋解答。

3.3 利用質場分析(S-Field analysis)與 76 標準解(76 Standard Solutions)進行深入設計探討

此部分是利用質場分析模型來對問題進行分類，找出質場(F)、物質 1(S1)、物質 2(S2)並對他們進行分析，以找出二者之間的關係，再利用 76 標準解解決問題。經由發明原則所提供的方向之後，歸納出問題導向碟盤排水效能不彰。 質場(F)為機械力—向心力，物件 1(S1)雨水，物件 2(S2)碟盤，而向心力作用在碟盤上不足以將水排開。此質場模型為圖 6.所示。

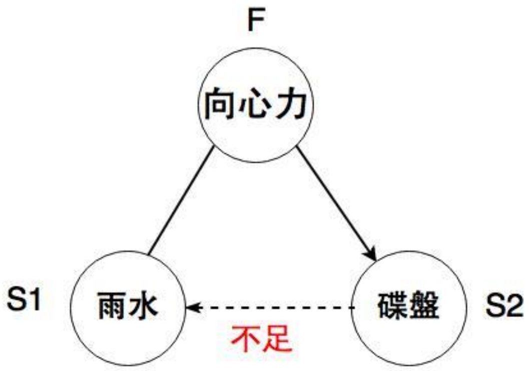

圖 6.問題模型

當水在煞車啟動時被壓入溝槽中，或在車輛行駛中在圓盤打轉，無法馬上排出碟盤外，套用的 76 標準解為第一類的 1.1.8，利用增加一個物體 S3 來針對問題進行解決，對於原先設計出的溝槽進行表面處理，讓溝槽中的摩擦力近於零(意即讓水一到溝槽上的凹縫時會因無法附著於金屬表面而噴飛或沿軌道迅速排出)如圖 7.所示。

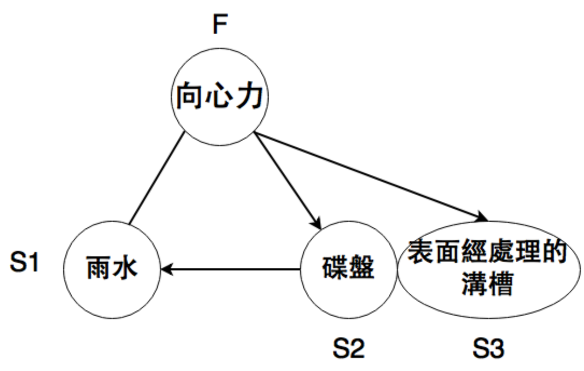

圖 7.解決模型

4. 煞車碟盤創新防沾水裝置

經過整合文章中所使用元件分析(Function analysis)設計探討、39 工程參數和 40 發明原則以及質場分析(S-Field analysis)與 76 標準解(76 Standard Solutions)進行深入設計等三個階段進行討論後，發現利用元件分析可迅速找出問題之發生因素，而矛盾矩陣可將原本基本之解決方案轉為有高可行性之創新發明，最後利用質場分析和 76 標準解修正與校訂最後的產品。藉由軸轉動帶動碟盤給予的向心力以及卡鉗的下壓力，設計出新式碟盤，能適用於市售一般普通重型機車，並不用特別改裝整組煞車系統，只需更換煞車碟片就可以使車子在雨天也可以有與晴天相同且穩定的制動力，本文概念設計之設計圖，如圖 8~圖 10 所示。

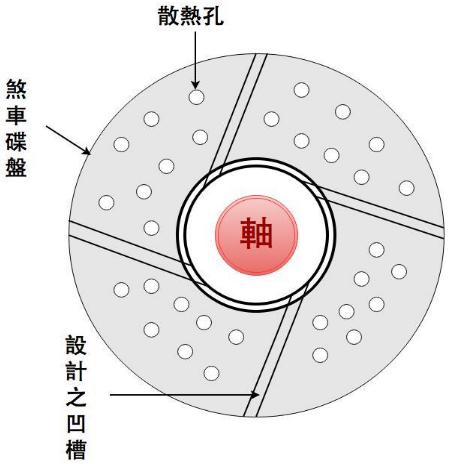

圖 8.煞車碟盤創新防沾水裝置(俯視圖)

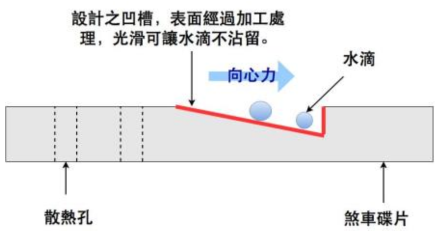

圖 9. 煞車碟盤創新防沾水裝置(側視圖)

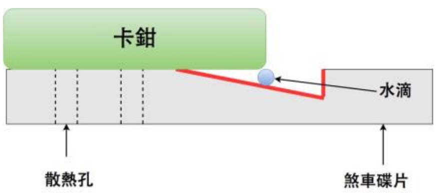

圖 10. 煞車碟盤創新防沾水裝置(除了向心力，也可利用機械力量加速排水)

5. 總結與未來展望

本文是藉由 TRIZ 為解決任務方法進行困難解決計畫任務，而本文所使用的三種常用方法為，元件分析(Function analysis)、39 工程參數和 40 發明原則、質場分析(S-Field analysis)與 76 標準解(76 Standard Solutions)。利用每種方法所提供的結果漸漸拼湊出可行性高且幾乎沒有副作用的解答，運用元件分析可以更明確地找出各零件互相作用之情形，之後使用兩種方法找出改良碟盤排水性的創意發想，此改良可望為更安全之煞車系統作一顆微小基石，也期待此項改良可真實應用於車輛當中，使駕駛在遇上類似突發狀況時能因此多一層保障。而此問題之解決也可證實，TRIZ 實際運用於專業領域的可行性和參考價值可靠度都不容忽視。

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翁永進博士自 2013 年以來在台灣嘉義大學當任教職。在此之前，他在國立中央大學、國立臺灣科技大學機械系與開南大學等學術單位分別擔任專兼任教職。翁教授從台灣大學獲得工學博士學位後，持續致力於創新研究與微系統製程開發為主要研究主題。他的研究領域包括微奈米壓印、精微與創新性之塑膠成型技術、微系統元件成形製程開發、TRIZ 研究。

陳重佑目前為國立嘉義大學機械與能源工程學系專題生。對於創新研究方法領域很感興趣，亦曾參加過 2017 系統性創新研討會暨論文競賽並進行口頭論文發表，表現良好。

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To Enhance the Display Factory's Flexibility of Material Management by Applying TRIZ

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Abstract

In order to control the manpower and production flexibility, many factories will choose to manufacture the components itself, few components will be outsourced, and later assembled into a monitor. There are many ways to outsource, including pure outsourcing foundry; complete outsourcing; partial outsourcing. All of these methods have affected the production elasticity and manpower utilization of the display factory. How to find the optimal management method for the key components of the display has become a very important issue. In the case study on the display factory, the purpose is to find out the most suitable and flexible material management. By applying the theory of TRIZ to find out the best flexible self-made or outsourced management of materials. The research can also provide the display factory a reference in the key components of self-made and outsourcing management. At the same time, it will enhance the flexibility of manufacturing and increase the overall efficiency of the display factory.

Keywords: Display, Production flexibility, TRIZ, Outsourcing management

運用萃智提升顯示器製造廠材料管理之彈性

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摘要

很多顯示器製造工廠，為了管控製造人力與生產的彈性，有些材料會選擇廠內自製，有些零組件則會選擇外包方式，最後再將各種材料組裝成顯示器。外包方式有很多種，包含單純外包代工、連工帶料外包、部分料客供外包等…，不同的方式會影響顯示器製造工廠的生產彈性與人力的運用，如何找出顯示器關鍵零組件最佳化的管理方式也成為很重要的課題。本研究係運用萃智理論問題模組，以顯示器製造廠為研究對象，將顯示器的關鍵材料分類，依各類別的品質、成本、交期產生的矛盾加以分析，找出各關鍵材料最適合之彈性材料管理方式，可提供顯示器製造廠針對關鍵零組件部材自組與外包管理之參考，提升顯示器製造工廠生產彈性，增加工廠整體效率。

關鍵詞：顯示器，生產彈性，萃智理論，外包管理。

1. 緒論

創新思維運用的目的，就是讓本研究具有「新的眼光」，克服思維的侷限，打破舊有的思維模式。一些看似困難的問題，如果本研究以新的眼光、新的思維，站到更高的位置，採用不同的角度來看待，就有可能得到新的答案；而萃智理論方法的運用，能夠幫助本研究突破思維定勢，從不同角度分析問題，揭示問題的本質，確定問題進一步探索方向，最終抓住機會來解決問題。

萃智理論方法多用來解決工程技術的問題，但其理論基礎可以廣泛用來解決很多領域問題，越來越多策略與管理面問題亦開始運用萃智理論方法，運用創新的思維，解決了策略與管裡面的問題。本研究係以顯示器製造工廠為例，分析其材料管理之問題點，藉以運用萃智理論找出顯示器製造產業材料管理之最佳彈性，提升顯示器製造工廠生產彈性，增加工廠整體效率。

1.1 研究背景與動機

本案研究之對象為一非標準長條屏顯示器製造工廠，所謂非標準長條屏顯示器即非一般消費性顯示器；一般消費性顯示器之螢幕尺寸比例為 4:3 或 16:9，而此顯示器製造工廠因具有專利之液晶面板切割技術，故可因應客戶不同尺寸的需求，提供客製化尺寸之液晶顯示器，解決消費者與客戶在侷限空間內需要顯示器之問題，產品應用也擴及廣告看板與工控交通運用之顯示器。

近年來，許多國家開始加快交通基礎設施的更新，歐洲、北美、日本和中國紛紛建設高速鐵路，為乘客提供了更舒適、更快捷的交通方式與在火車上的資訊獲取，讓乘客在乘車期間更清楚相關交通與到站資訊。這些非標準長條屏顯示設備透過此製造工廠專業技術研發與製造，增加了防震、抗衝擊、低能耗和寬溫度範圍的特殊設計，更結合動態地圖播放，嵌入式電腦的中央平台，可用於車內有限空間中，提供車內主要資訊給予乘客。

由於軌道交通市場需求越來越大，客戶不同尺寸的顯示器需求也日益增多，從研發到備料到生產製造的時程要求也越來越短，人力控

制與生產彈性也日趨重要。為了管控製造人力與生產彈性，有些材料會選擇廠內自製，有些零組件則會選擇外包方式，最後再將各部材組裝成顯示器，但外包方式有很多種，包含單純外包代工、連工帶料外包、部分料客供外包等…，這些方式或多或少影響了顯示器製造工廠的生產彈性與人力的運用，如何找出顯示器關鍵零組件的最佳化的管理方式也成為很重要的課題。

與研究對象之顯示器製造工廠經營團隊訪談後得知，在各種解決問題的方式中，傳統材料外包的考量是非常單向的，多以「成本」作為考量依據，但實際操作上，往往會發生外包供應商無法滿足開發時程、無法配合改善品質、無法達成交期要望等衝突問題。而系統性的萃智理論方法，可將顯示器的關鍵部材分類，依各類別的品質、成本、交期產生的矛盾加以分析，找出各關鍵部材最適合之彈性材料管理方式。

2. 研究方法

本章主要說明萃智理論方法解題步驟流程(趙敏、史曉波、段海波，2012)，如圖 1。依照系統性創新流程逐步走完各個步驟，先將管理問題界定並將問題加以分析，建立矛盾矩陣，利用萃智管理性的發明原則得到問題最佳答案模式，依解答模式實施後評估實際實施成效。

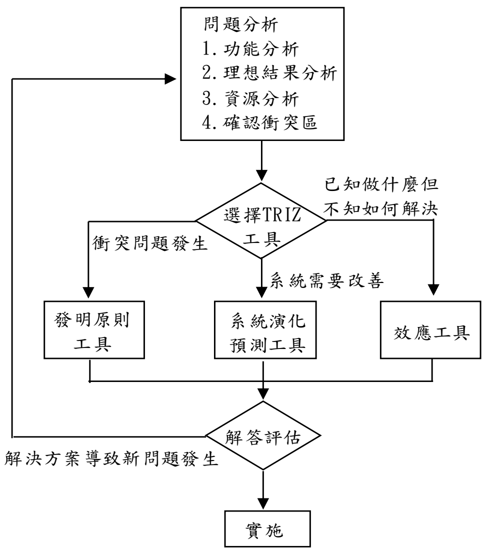

圖 1. 萃智管理問題求解模式

資料來源：本研究參考趙敏、史曉波、段海波(2012)，《TRIZ 入門與實踐》修改繪製

2.1 SWOT

本研究參考何應欽(2016)，SWOT 分析修訂後整理，如表 1。優勢與劣勢分析主要是著眼於企業自身的實力及其與競爭對手的比較，而機會和威脅分析將注意力放在外部環境的變化及對企業的可能影響上。在分析時，應把所有的內部因素（即優劣勢）集中在一起，然後用外部的力量來對這些因素進行評估。

(1) 優勢與劣勢分析

每個企業都要定期檢查自己的優勢與劣勢，這可透過「企業經營管理檢核表」的方式進行。當兩個企業處在同一市場或者說它們都有能力向同一顧客群體提供產品和服務時，如果其中一個企業有更高的營利潛力，一般人就認為這個企業比另外一個企業更具有競爭優勢。競爭優勢可以指消費者眼中一個企業或它的產品有別於其競爭對手的任何優越的東西，它可以是產品的大小、品質、可靠性、適用性、風格和形象以及熱情的態度、及時的服務等。雖然競爭優勢實際上指的是一個企業比其競爭對手有較強的綜合優勢，但是明確企業究竟在哪一個方面具有優勢更具意義，因為只有這樣，才可以揚長避短。

企業在維持競爭優勢過程中，必須深刻認識自身的資源和能力，採取適當的措施，一個企業一旦在某一方面具有了競爭優勢，勢必會吸引到競爭對手的注意。一般來說，企業經過一段時期的努力，建立起某種競爭優勢，然後就處於維持這種競爭優勢的態勢，競爭對手開始逐漸做出反應；如果競爭對手直接進攻企業的優勢所在，或採取其它更為有力的策略，就會使這種優勢受到削弱，如此一來，就會競爭的劣勢。

(2) 機會與威脅分析

隨著經濟、科技等諸多方面的迅速發展，特別是世界經濟全球化、一體化過程的加快，全球信息網路的建立和消費需求的多樣化，企業所處的環境更為開放和動蕩。這種變化幾乎對所有企業都產生了深刻的影響。正因為如此，環境分析成為一種日益重要的企業職能。環境發展趨勢分為兩大類：一類表示環境威脅，另一類表示環境機會。環境威脅指的是環境中一種不利的發展趨勢所形成的挑戰，如果

不採取果斷的戰略行為，這種不利趨勢將導致公司的競爭地位受到削弱。

表 1. SWOT 分析

優勢 (Strength)	劣勢 (Weakness)
1. 目前擁有何種優點 2. 目前擅長項目為何 3. 可使用哪些資源 4. 他人將該項目視為是我們的優勢	1. 目前需改進之處 2. 目前不擅長之處 3. 最需要避免之處
機會(Opportunity)	**威脅 (Threat)**
1. 目前處於機會點的何處 2. 是否察覺任何特別的趨勢 3. 政府政策是否帶來新的機會 4. 技術或市場變遷所產生的機會	1. 將面臨何種障礙 2. 競爭對手的動向 3. 需求項目是否正在改變 4. 技術變遷影響定位 5. 呆帳等財務問題

資料來源:本研究參考何應欽 (2016)，《作業管理》修改繪製

2.2 顯示器的組成與關鍵材料分類

隨著網際網路與無線電通訊技術的急遽發展，資訊化漸漸普及於個人，因此可攜式資訊產品，如筆記型電腦、行動電話、數位相機等，均快速發展與成長。由於液晶顯示器具有薄型化、輕量化、低耗電量、無輻射污染等優點，並順應著這股網際網路數位資訊化市場的興起，使其在短短幾年間，產品應用更是飛躍性的成長。其技術涵蓋材料、設備、製程、產品特性等諸多層面的開發，真可謂是一日千里。

一般來說，顯示器的組成與關鍵材料大致可分為背光模組、液晶面版、系統電路板、機構件四大關鍵材料，本研究參考黃素真(2002)液晶顯示器之組成修訂後整理，如表 2；其中背光模組又細分為燈條 LIGHTBAR、光學膜片、導光板與機構件，如圖 2。

表 2. 液晶顯示器之組成

液晶顯示器組成之關鍵部材
背光模組
液晶面板
系統電路板
機構件

資料來源:本研究參考黃素真 (2002)，《液晶顯示器，科學發展，349，31-33》修改繪製

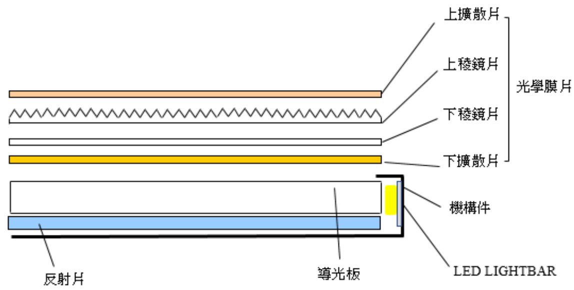

圖 2. 背光模組組成圖

資料來源:本研究參考黃素真 (2002)，《液晶顯示器，科學發展，349，31-33》修改繪製

2.3 矛盾矩陣

矛盾矩陣是萃智理論常用的工具，是前蘇聯學者 Genrich S. Alshuller 將 39 個通用工程參數與 40 項發明原理有機地聯繫起來，建立起對應的關係，整理成 39×39 的矛盾矩陣表。

矛盾矩陣更是 Alshuller 對 250 萬份專利進行研究後所取得的成果，矩陣的構成非常緊密，本研究可以根據系統中產生矛盾的 2 個通用工程參數，從矩陣表中直接查找出化解矛盾的發明原理，並使用這些原理來解決問題。

在策略與管理的矛盾衝突中，Darrell L. Mann 博士把 39 個技術參數轉化成 31 個管理性的參數，如表 3。

表 3. 管理衝突的矩陣參數

Business & Management	
1. R&D Spec/Capability/Means	17. Support Cost
2. R&D Cost	18. Support Time
3. R&D Time	19. Support Risk
4. R&D Risk	20. Support Interfaces
5. R&D Interfaces	21.Customer Revenue/Demand/Feedback
6. Production Spec/Capability/Means	22. Amount of Information
7. Production Cost	23. Communication Flow
8. Production Time	24. System affected

	harmful effects
9. Production Risk	25. System generated side effects
10. Production Interfaces	26. Convenience
11. Supply Spec/Capability/Means	27. Adaptability/Versatility
12. Supply Cost	28. System Complexity
13. Supply Time	29. Control Complexity
14. Supply Risk	30. Tension/Stress
15. Supply Interface	31. Stability
16. Product Reliability	

資料來源：本研究參考 Darrell L. Mann (2002a)，《Systematic win-win problem solving in a business environment. The TRIZ Journal.》修改繪製

2.4 萃智理論

萃智理論是前蘇聯學者 Alshuller 在 1946 年帶領他的研究團隊分析近 250 萬筆的發明專利文件，總結出各種技術發展進化遵循的規律模式，以及解決各種技術矛盾和物理矛盾的創新原理和法則，建立一個由解決技術，實現創新開發的各種方法、演算法組成的綜合理論體系，並綜合多學科領域的原理和法則，建立起萃智理論體系。

萃智理論中，常見的工具是矛盾矩陣，由 39 個工程參數與 40 項發明原則所組成。矛盾的形成是 39 個工程參數開發期間，所產生的技術和物理矛盾，40 項發明原則係由專利分析中歸納的經驗法則，由二者的參數的聯結得到產品改良的具體方案。

本研究以顯示器製造廠為研究對象，將顯示器的關鍵材料分類，依各類別的品質、成本、交期產生的矛盾加以分析，並利用 40 個發明原則找出顯示器製造產業材料管理之最佳彈性，可提供顯示器製造廠針對關鍵零組件材料自製與外包管理之參考，提升顯示器製造工廠生產彈性，增加工廠整體效率。

3. 問題描述與解題步驟

研究對象之顯示器製造工廠由於多為客製化生產，並為接單式生產，依客戶訂單數量與型號批量性生產，故管控製造人力與生產的彈性就極為重要。當訂單量增加時，為了不增加固定人工成本增加生產彈性，許多顯示器組裝所需之材料就會選擇外包生產。與研究對象之顯示器製造工廠經營團隊訪談後得知，外包方式的評估往往在初期僅以「成本」為單一考量依據，但成本和品質、交期常常產生矛盾；外包供應商時常不對品質負責，甚至交期無法滿足開發時程要望，若需要嚴格管控品質，外包供應商又要加價，此時就產生額外之品質成本與失敗成本，這些都是初期評估會遺漏的，如何找出一個適當的材料管理最佳方式就成為此研究之主要課題。

3.1 SWOT

對於研究對象之顯示器工廠，進行 SWOT 分析與研究，藉由資料分析出可以找出此顯示器工廠導入材料外包管理之成效。此顯示器工廠在過去的幾年中取得了令人矚目的成功，其中一個顯著的原因就在工廠對其內部環境進行了積極的變革，公司的內部環境分析幫助其確立公司內部許多方面的優勢和劣勢。但因市場變化迅速，客戶對顯示器尺寸的需求也越來越多樣化，此顯示器工廠產品開發進度若跟不上客戶需求的要望時程，很多工控或軌道交通應用之顯示器的訂單就會因此而受到影響。然而，如何提升產品開發進度來滿足客戶需求的時程，就成為顯示器工廠產品開發的重要議題。與本研究對象之顯示器工廠管理團隊訪談所做出此顯示器工廠分析，如表 4。

表 4. 研究對象之顯示器工廠 SWOT 分析表

優勢 (Strength)	劣勢 (Weakness)
1. 完善的客製化服務 2. 面板資源取得容易 3. 一條龍的開發與生產 4. 專利 Panel 切割技術，領先競爭對手	1. 原料成本高昂 2. 因客製化商品多，組裝效率不佳 3. 開發時程太長不及顧客需求
機會 (Opportunity)	**威脅 (Threat)**
1. 大陸軌道交通應用市場佔有率 70%，消費者接受度高 2. 依客戶需求客製顯示器尺寸	1. 客戶需求太急，需求顯示器尺寸種類太雜太廣 2. 大陸市場的價格競爭

3. 產品應用範圍廣，取代傳統 LED 跑馬燈 4. E 化世代，可連結軟硬體的互動	3. 顯示器大廠工控部門競爭

(1) 開發效率與時程和成本的矛盾

在客製化產品的需求下，客人往往希望在 2-4 週內就有樣品可以送樣，但此顯示器製造工廠目前的外包供應商第一次產出顯示器材料時程約 4-6 週，研發單位需整合外包生產之材料做新機種的開發，新機種圖面製作加上供應商收到圖面後製作物料的時間過長，致使整體新機種開發時程需要 8-12 週，若物材需加快入手，成本必須增加 2-3 倍，導致開發效率與時和成本產生矛盾。

(2) 品質良率與成本的矛盾

為握有成本自主管控權，目前此顯示器工廠外包方式為提供物料給代工廠外包生產，但代工廠僅依代工成本代工生產物材，並不考量顯示器工廠提供之物料品質水準是否符合產品需求，代工入手之材料品質無法滿足最終產品之品質良率，造成良率不佳，形成品質良率與成本間之矛盾。

(3) 生產效率與成本的矛盾

此顯示器工廠雖部分材料外包生產，保有較佳生產彈性，但因外包品質不良影響整體生產效率，最終產品重工之頻率也同時增加，所以若僅以成本作為考量依據的物材外包評估方式，不僅對於品質良率產生影響，也影響工廠整體效率，故生產效率與成本也產生矛盾。

3.2 顯示器的組成與關鍵部材分類

分別針對顯示器四大關鍵材料來研究哪些材料適合評估以外包方式生產。

(1) 背光模組

在顯示器的關鍵材料中，背光模組最主要提供給顯示器必要的光源。液晶面板本身並不會發光，需由背光模組提供適當光源後才能看到液晶面板之呈像，但背光模組的組裝和管理，在顯示器製造廠中較為複雜，因其組成零組件很多，每樣零組件都可能影響背光模組發光效率及品質，很多顯示器工廠的背光模組都會交由專業背光模組廠生產，以減少本身管理之負擔，但若需縮減開發時程，背光模組亦可能選擇自製，故背光模組的外包或自製就是一個重要的課題。此研究可由萃智理論方法找出最佳答案。

(2) 液晶面板

液晶面板為液晶顯示器最主要之材料，此顯示器工廠主要生產製造非標準長條屏顯示器，其擁有專利液晶切割技術，可依客戶不同尺寸之需求切割製造，屬特殊客製化與高技術性製程，且此專利技術為該工廠核心製程與技術，具市場商業機密之價值，不宜外流，故液晶面板之切割不適合採用外包方式生產製造。

(3) 系統電路板

因應客戶和市場需求創造出新的廣告平台與多元化的產品。此顯示器工廠的技術人員涵蓋 IT、TFT-LCD 與網通技術背景，還有軟件開發團隊、硬件設計團隊與產品工程部門，可以快速因應客戶需求及提升開發彈性與效率。系統電路板雖自行開發，但此顯示工廠並無建置系統電路板製作之相關設備與機台，系統電路板全數採用外包生產，故必須找到外包管理方式之最佳方式，對整體工廠運行才更有幫助。

(4) 機構件

機構件為撐起顯示器之重要骨架，機構件為沖壓成型，必須有相關機台設備，此顯示器工廠無相關機台設備，皆以外購入料生產，唯機構件較為單純，購入即為素材，故直接依採購件採購，非外包管理相關物料，不適用此研究範圍。

3.3 矛盾矩陣

利用 Mann 博士 31 個管理性的參數，建立彼此對應關係，再根據此研究中產生矛盾的 2 個通用的主要問題，從矩陣表中直接查找出化解矛盾的發明原理，並使用這些原理來解決問題。

表 5. 管理性矛盾矩

	Worsening Factor->	R&D Spec/ Quality/ Capability	R&D Cost	R&D Time	R&D Risk	R&D Interfaces	Production Spec/ Quality/ Means	Production Cost	Production Time	Production Risk	Production Interfaces	Supply Spec/ Quality/ Means	Supply Cost	Supply Time	Supply Risk	Supply Interfaces	Product Reliability
	Improving Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	R&D Spec/ Quality/ Capability		2,4,15,38	1,38,35,23,1	9,24,23,36,	13,24,33,38,	23,29,35,4	37,35,10,6	35,6,10,20	3,5,10,11	5,37,14	6,2,35	15,6,1,5	2,3,12,26	11,39,30,31	11,26,2,5	36,11,2,35
2	R&D Cost	2,4,15,38		26,34,1	27,9,34	13,26,35,1	5,2,27,1	6,35,1,27,3		6,7,23,26	15,35,25	23,6,11,28				10,38	27,6,1,10
3	R&D Time	1,38,35,23,1	26,34,1		1,29,10,11	15,25,35,1	5,6,20,35	5,29,35		6,15,7,37	25,23,35,29	1,6,23,19,1				11,7,40,38	6,10,3,35
4	R&D Risk	9,24,23,36,	27,9,34	1,29,10,11		,29,15,14,1	4,35,10,3,1	5,35,40,23	5	1,23,39,7,3	7,3,17,23	5,6,35	1,11,2	1,2,11,38		13,22,25	6,1,26,37
5	R&D Interfaces	13,24,33,38,	13,26,35,1	15,25,35,1	,29,15,14,1		5,6,17,40,3	15,23,29,5	15,40,23	7,5,3,37	28,40,6,29	6,35,13,14	2,33,3	5,2,35	5,35,13,40	8,40,6,15,2	6,1,3,35
6	Production Spec/ Quality/ Means	23,29,35,4	5,2,27,1	5,6,20,35	4,35,10,3,1	5,6,17,40,3		15,25	1,35,21,15	6,27,35,22	3,25,17,35	7,13,22,6	15,35,13,22	35,5,13,22	15,16,3,2	10,25,3,33	35,23,1,24
7	Production Cost	37,35,10,6	6,35,1,27,3	5,29,35	5,35,40,23	15,23,29,5	15,25		1,24,19,27,3	26,10,1,3	26,1,37,2	5,2,30,35	5,35,31	2,35		12,3,35,5	1,35,10
8	Production Time	35,6,10,20			5	15,40,23	1,35,21,15	1,24,19,27,3		),27,15,6,3,	,15,38,20,2	5,17,16,3	5,2,35	3,10,23,40		23,12,3	1,35,10,38
9	Production Risk	3,5,10,11	6,7,23,26	6,15,7,37	1,23,39,7,3	7,5,3,37	6,27,35,22	26,10,1,3	),27,15,6,3,		5,6,23,20,7	5,25,3,35	5,35,23,25	13,22	5,26,35,2	5,10,40,2,4	13,35,2,15
10	Production Interfaces	5,37,1,4	15,35,25	25,23,35,29	7,3,17,23	28,40,6,29	3,25,17,35	26,1,37,2	,15,38,20,2	5,6,23,20,7		6,2,37,40	5,30	5,35,6,13,17	23,33,5,26,2	33,5,2,26	23,11,40,2
11	Supply Spec/ Quality/ Means	6,2,35	23,6,11,28	1,6,23,19,1	5,6,35	6,35,13,14	7,13,22,6	5,2,30,35	5,17,16,3	5,25,3,35	6,2,37,40		7,35,19,1	35,1,13,2	7,8,11,10,24	6,30,15,40	11,23,35,1
12	Supply Cost	15,6,1,5			1,11,2	2,33,3	15,35,13,22	5,35,31	5,2,35	5,35,23,25	5,30	7,35,19,1		,24,38,10,1	27,3,19,24,8	1,28,6,38,4	35,24
13	Supply Time	2,3,12,26			1,2,11,38	5,2,35	35,5,13,22	2,35	3,10,23,40	13,22	5,35,6,13,17	35,1,13,2	,24,38,10,1		10,29,15,13	5,19,3,15	
14	Supply Risk	11,39,30,31				5,35,13,40	15,16,3,2			5,26,35,2	23,33,5,26,2	7,8,11,10,24	27,3,19,24,8	10,29,15,13		5,25,37	
15	Supply Interfaces	11,26,2,5	10,38	11,7,40,38	13,22,25	8,40,6,15,2	10,25,3,33	12,3,35,5	23,12,3	5,10,40,2,4	35,5,2,26	6,30,15,40	1,28,6,38,4	5,19,3,15	5,25,37		10,31,24,35
16	Product Reliability	36,11,2,35	27,6,1,10	6,10,3,35	6,1,26,37	6,1,3,35	35,23,1,24	1,35,10	1,35,10,38	13,35,2,15	23,11,40,2	11,23,35,1	35,24			10,31,24,35	
17	Support Cost	15,29,35	6,1,10,25	7,15,40,26	11,7	6,7,40,38	13,10,17,2				23	23,11				5,10,26,1	2,25
18	Support Time	5,2,6,27	6,1,10,27	7,40,1,26		6,38,20,10	5,6,10,12				23	23,11				29,30,2,5	22,25
19	Support Risk	15,27,40			0,36,6,10,2	5,35,40,13	6,10,2			7,5,3		11,23,24,2			24	5,10,9,2	13,22
20	Support Interfaces	11,2,5,9,26	6,1,10	6,10,26	6,10,7,26	28,40,6	6,40			5,35,33	40,33,6	23,11,2	24	24,5	5,35	5,6,38,40	28,25,5,7
21	Revenue/ Demand/ Feedback from	14,13,22,7	7,25,30,21	,19,21,29,3	36,13,25,22	4,7,25,40	,15,35,25,3	7,13,1	13,1	13,22	7,5,10,40,4	10,3	2,35,13,25	35,13,25	25,22,2,35	13,25,39,24	28,25,7,22
22	Amount of Information	37,13,25,39	37,25,28,32	7,2,37,20	1,3,4,10	1,6,3,40	2,15,23,24,1	26,27,25,34	13,15,23	5,25,3,37	2,37,4,13	13,4,28,17	8,35,2,37,3	28,2,32,35	5,37,15,6,3	3,6,37,28,3	10,28,3
23	Communication Flow	6,25,31,29	6,18,37	,26,18,19,4	30,6,31	2,6,35,3	6,2,13,25	6,35,37,18	2,37,18,19	5,38,3,26,1	2,28,3,37,3	5,25,23	35,6,1,27	6,31,16,35	6,16,13,35	2,3,13,4,12	10,28,37,3
24	System Affected Harmful Effects	11,25,2,26,3	35,27,3,28	26,2,35,24	35,2,15,26,3	3,26,35,28	,24,35,13,2	2,35,5,34	22,35,13,24	35,2,26,34	3,26,35,28	13,17,29,2	11,35,2,3	35,3,29,2	2,13,35	3,35,13	7,35,34,2,4
25	System Generated Harmful Effects	5,29,2,37,1	28,26,2,22,8	6,2,15,19,3	2,3,35,15	,26,35,37,4	35,22,18,39	1,35,27,10,2	5,22,18,10,2	25,10,39,24	3,26,35,29	0,1,34,35,1	0,35,2,12,3	25,10,29,13	,15,19,23,4	2,30,40,22	35,40,24,26,
26	Convenience	15,35,25,16	25,2,6,5,40	1,2,15,19,28	26,3,11,24	16,13,25	5,28,7,10,1	1,25,2,27	19,2,35,26	3,26,6,11	5,19,28,32	35,3,13,2	30,2,3,5	24,35,28,1	5,16,10,13	5,25,3,40	27,17,40,8
27	Adaptability/ Versatility	30,25,29,1	35,28,8,1	15,1,35,14,4	,40,31,28,3	9,37,40,1,1	15,17,2,28,	1,30,10,38	10,15,30,7	,40,38,30,3	9,1,17,40,3	13,17,7,15	1,17,40,3	15,1,10,27	15,17,40,3	29,28,30,3	35,13,8,24
28	System Complexity	17,25,1,19	5,2,35,1	5,6,25,2	28,30,35,1	25,28,1,3	,27,26,1,28,	35,5,1,2	25,28,2	25,2,26,5	10,18,28,2	9,30,35,17,	35,19,1,25,2	38,24,16,15	2,4,15,28	28,5,3,37,40	13,35,1
29	Control Complexity	25,15,19,35	5,19,2,37,3	25,28,15,2,6	25,1,3,37,40	6,28,1,3,40	28,1,13,16,	6,3,25,32	25,37,3,13	0,12,25,40,	,28,19,15,4	6,5,28,37,3	22,2	28,32,2,37	2,28,15,24	5,8,22,28,3	11,13,2,35
30	Tension/ Stress	3,2,25,35	1,19,35,27	2,39,24,10	1,23,2,25	35,3,37,32	35,1,3,10,16	1,35,2,25	2,20,25,3	25,9,24,39	3,40,19,1,24	2,23,5,30	10,3,7,40	1,10,15,24	1,19,13	5,3,17,29	11,35,24,19
31	Stability	36,25,15,29	11,25,27	10,27,35,22	9,1	15,17,36,3,4	3,19,13,11,	10,1,35,27	0,15,29,2,1	9,1	11,25,1,3,4	15,5,10,35	19,3,10	35,3,5,27	9,13,1	3,15,23,17,	

資料來源：本研究參考 Darrell L. Mann (2002b) ，《Hands on systematic innovation. CREAX Press.》

(1) **背光模組的管理性矛盾**

在追求彈性生產的過程中，背光模組的外包生產通常是第一個被提出檢討的。一般外包生產的考量往往僅考量「成本」，若成本計算出來比廠內自製還有優勢的話，通常直接就會選擇外包生產，背光模組因為部材較多較繁雜，通常是以連工帶料的方式外包，外包供應商生產的背光模組必須符合顯示器尺寸外觀、電氣、品味等規格需求。

背光模組外包最主要的矛盾在於成本與外包供商的品質和交期，將不要惡化的參數定義為成本；需要改善的參數定義為供應商品質與交期，如表 5。

本研究參考 Darrell L. Mann (2002b)修訂後整理，將主要問題矛盾引出，再從矛盾矩陣找出最佳解答方案，如表 6。

表 6. 背光模組外包生產管理矛盾

<table>
<tr><th colspan="3">背光模組外包生產管理矛盾</th></tr>
<tr><td colspan="2" rowspan="2">不希望惡化的
要改善的參數</td><td>產品成本</td></tr>
<tr><td>7</td></tr>
<tr><td>1</td><td>供應商規格/品質工法</td><td>5.2.30.35</td></tr>
<tr><td>3</td><td>供應商時間</td><td>2.35</td></tr>
</table>

(2) **系統電路板的管理性矛盾**

系統電路板大部分為外包生產，目前此顯示器製造工廠外包方式為部分物料由顯示器工廠提供，部分物料連工帶料外包代工生產，矛盾點產生在外包廠商並不負責顯示器工廠提供之物料品質，因物料品質不良時常造成交期延誤，交期延誤就會影響開發時程。故將不要惡化的參數定義為交期與成本；需要改善的參數定義為供應商的品質，將主要問題矛盾引出，再從矛盾矩陣找出最佳解答方案，如表 7。

表 7. 系統電路板外包生產管理矛盾

<table>
<tr><th colspan="4">系統電路板外包生產管理矛盾</th></tr>
<tr><td colspan="2" rowspan="2">不希望惡化的
要改善的</td><td>產品成本</td><td>產品時間</td></tr>
<tr><td>7</td><td>8</td></tr>
<tr><td>1</td><td>供應商
規格/品質/工法</td><td>5.2.30.35</td><td>5.17.16.3</td></tr>
</table>

3.4 萃智理論

萃智理論中的發明原理是由專門研究人員對不同領域的已有創新成果進行分析、總結，得到的具有普遍意義的經驗，這些經驗對指導各領域的創新都有重要參考價值。常用的發明原理有 40 個，實踐證明這些原理對於指導設計人員的發明創造具有重要的作用。當找到確定的發明原理以後，就可以根據這些發明原理來

考慮具體的解決方案。可從上述矛盾矩陣中，分別找出最佳解答方案。

(1) 萃智理論方法解決背光模組的矛盾

背光模組外包矛盾於萃智理論中的觸發方案，如表 8。

表 8. 背光模組萃智觸發解表

	發明原則	觸發解/應用方案
1	2 分離/抽取原則	取消原背光模組外包方式,將背光模組外包從流程中抽離
2	5 合併原則	將背光模組生產與工廠生產流成合併，以自製方式生產背光模組
3	30 彈性殼與薄膜原則	背光模組設計輕薄化,可以減少物料成本
4	35 參數改變原則	背光模組設計參數規格檢視,依廠內顯示器規格判定,可覆蓋單純背光模組之不良

依表 8 得到最佳方案，本研究建議顯示器製造工廠的背光模組外包生產從流程中抽離，背光模組生產可與工廠生產流成合併，以一條龍方式自製化生產，除了可以增加效率外，在品質面工廠可通盤掌控，規格判定亦可直接依廠內顯示器規格判定，可覆蓋單純背光模組之不良，提高整體生產品質直通率。

本研究對象之顯示器製造廠在工廠原有的設備建置下，經內部整合評估，背光模組自製生產可與原顯示器生產製造之相關工作台桌與設備共用，不需額外花費其他設備建置成本，故在背光模組的外包管理上，依本研究建議之最佳方案導入自製化生產。

整體而言，除了增加效率外，在品質管控方面，規格判定亦可直接依廠內顯示器規格判定，可覆蓋單純背光模組之不良現象，提高整體生產品質直通率。

本研究對象之顯示器製造工廠導入背光模組自製生產後成效如下,相關數據來源:本研究對象之顯示器製造工廠提供

a. 整體生產效率

背光模組以外包生產,供應商常常無法如期交貨或是外包背光模組入料檢品質不良，導致工廠端無背光模組可以組裝成液晶顯示器，工廠端必須臨時安排人員切換其他工作，易產生缺料等待與切換線的浪費，影響整體生產效率，整體生產效率為 78%。本研究對象之顯示器製造廠依本研究建議之最佳方案導入背光模組自製生產後，背光模組生產時程可由工廠端直接管控，生產排程依一條龍方式安排，從背光模組組裝到 LCM 模組組裝到液晶顯示器的生產皆由工產端直接管控與生產製造，解決了工廠端缺料等待與切換線的浪費，整體生產效率提升至 90%，生產效率提升 12%。

b. 開發時程

背光模組外包生產，供應商開發背光模組的時程為 4-6 週，研發單位需整合外包之背光模組做新機種的開發，新機種圖面製作加上供應商收到圖面後製作物料的時間過長，致使整體新機種開發時程需要 8-12 週。本研究對象之顯示器製造廠依本研究建議之最佳方案導入背光模組自製化生產後，所有設計掌握在研發單位手上，液晶顯示器新機種的開發整合容易，圖面製作與機構設計開發一體化設計，新機種整體開發時程縮短為 4-6 週，新機種開發效率提升 50%。

c. 品質直通率

背光模組外包生產，工廠端入料檢依背光模組檢驗規範檢驗，單背光模組檢驗規範較嚴苛，整體品質直通率為 82%。本研究對象之顯示器製造廠依本研究建議之最佳方案導入背光模組自製化生產後，品質檢驗依液晶顯示器檢驗規範檢驗，有些在背光模組上的異常現象，在組裝上液晶面板後，依整體液晶顯示器規格判定 OK 即視為良品，故品質直通率提高至 96%，整體品質直通率提升 14%。

(2) 萃智理論方法解決系統電路板的矛盾

系統電路板外包矛盾於萃智理論中的觸發方案，如表 9。

表 9. 系統電路板萃智觸發解表

	發明原則	觸發解/應用方案
1	2 分離/抽取原則	取消原系統電路板客供物料外包方式，將客供物料從系統電路板外包抽離
2	3 局部品質原則	將系統電路板外包品質結合廠內整機品質作評估
3	5 合併原則	將系統電路板外包方式全數合併為連工帶料方式外包，外包供應商必須對品質全數負責
4	16 不足或過多的作用原則	將品質要求簡化，要求供應商整體系統電路板的品質，對於系統電路板的物料由供應商管控
5	17 改變空間維度原則	將多個功能的系統電路板整合至一塊系統電路板, 電子物料由同一外包供應商管控
6	30 彈性殼與薄膜原則	系統電路板設計優化
7	35 參數改變原則	系統電路板設計參數規格檢視，依廠內顯示器規格判定

依表 9 得到最佳方案，本研究建議顯示器工廠取消原系統電路板客供物料外包方式，將客供物料從系統電路板外包管理方式中抽離，以全數合併為連工帶料方式外包生產，另將品質要求簡化，讓供應商自行管控系統電路板之小零件品質，進而對於外包之系統電路板之品質交期作確保，顯示器工廠僅對於整體系統電路板管控並依廠內顯示器規格判定即可。此方案對於顯示器工廠在系統電路板的管控上較容易，品質、交期、開發時程上也容易掌握。

4. 結論

此研究運用系統性創新的研究方法運用在實務製造廠材料管理與策略上，提供顯示器製造廠不同的創新思維，提升整體效率與競爭力，並且解決解決製造廠材料管理造成的品質成本交期的衝突與矛盾。

利用萃智理論矛盾矩陣與 40 項發明原則得知顯示器製造廠之背光模組宜採用自製生產，對於品質、成本、交期皆更有競爭力；而系統電路板需採取連工帶料方式外包，讓供應商自行管控系統電路板之小零件品質，進而對於外包之系統電路板之品質交期作確保，顯示器工廠在系統電路板的管控上也較容易，品質、交期、開發時程上也容易掌握。

整體而言，萃智理論方法為顯示器製造廠提供一個系統性創新的方法，解決管理或策略問題，找出顯示器製造廠材料管理之最佳化彈性，提升此顯示器製造廠之生產彈性，增加整體效率。

未來可將此理論方法擴展應用於其他製造工廠，另外，對於不同領域的管理與策略問題，皆可以運用相同之系統創新發法來解決，藉以提升產業整體效率與競爭力，進而促進國內產業發展，提升國家競爭實力!

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黃文正是國立成功大學工學院工程管理碩士在職專班碩士。目前為 LWO 凌暉科技股份有限公司廠長暨業務行銷總監，本身在 LCD 顯示器製造產業已有超過 15 年的業界經驗，專業領域包含系統性創新、生產製造管理、設備管理與工廠診斷。

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Altshuller, G.,1998. *40 Principles: TRIZ Keys to Technical Innovation*, Technical Innovation Center.

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