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The Use of DFSS Tool / Design for Six Sigma in the Innovative Process of New Product Development: a Case Study

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Abstract

The DFSS methodology is being widely used as a quality management model. Focusing on "Zero Defects" production, the tool that support DNP used in the planning phases, that precede manufacturing is DFSS methodology, suitable for production processes with SS requirement. There is a contradictory question regarding the differences and complementarities between DFSS tool and the SS methodology: to conclude about what is the best strategic decision by two companies, in which one uses the SS and the other uses the DFSS; else more, if it would be a competitor at a higher level with regard to the experience and knowledge, by using both. The case study indicates that given the intrinsic characteristics of the company, common to other Portuguese Small, Medium Enterprises (SMEs), it is clear that the use of DFSS tool turns out to be the most effective, especially when the client is a big company.

Keywords: Design for Six Sigma (DFSS), New products development, Six Sigma (SS).

1. Introduction

Motorola enterprise faced a problem in the past. The company was losing market and needed to find the cause of such problem. Even after testing several tools already used by other companies, still couldn't be competitive enough. However, after several studies, it became possible to confirm that the stock of waste, material, time and manufacturing defects, were generating high costs. Then Bill Smith, a Motorola engineer, in 1986, created the Six Sigma methodology (Suski and Maukiewicz, 2010), which replaced the program TQM (Total Quality Management). This methodology has brought very positive results and after its release, it has been implemented worldwide in many organizations such as: General Electric, Ford, Caterpillar, Microsoft, Raytheon, Siemens, Citybank, and others. The SS methodology has this name because, according to Cone (2001, p.31) the letter sigma is the Greek letter that represents the statistical unit of measurement that defines the standard deviation of a population. It measures the variability or data distribution. The higher the sigma, better are the products produced or services, and from another point of view, the less are the defects presented by these products and services. So with the application of this methodology, it is possible the realization of products and services with only 3.4 defects per million of the units produced.

The SS methodology (Six Sigma) is used for strategic changes. It is an organizational approach to the excellence of performance, the persistent search of perfection to answer the customer needs, decision making driven by data and facts, process improvement, strict alignment of actions with the strategies and the measurement the ultimate impact. (Pande, 2001). In this conditions, the design and develop of new products with this goal of perfection offered by SS philosophy, is essential to its success in the market and for the achievement of its effectiveness (Dias, 2015; p 128.). The DFSS tool is an alternative to this, it is an approach to product development that integrates effective analytical methods, to ensure that the design is: oriented to the customer (voice of customer); innovative; robust against the causes of variation and have a minimum total cost. (Mader, 2003) The approach based on DFSS becomes more suitable to the creation and development new products, services and processes, not so much in the improvement of existing ones, getting this aspect and the curative nature of interventions for the SS

(Dias, 2015). The DNP is the launch of new products that is increasingly common in the Portuguese industrial sector instead of non-innovative and less value-added industries. In this research directed to the DNP, the right tool for the design phase, is the DFSS and instrumental tools that are DMADV cycle (Define, Measure, Analyze, Design, Verify), and all that have developed from this one. These cycles represent the various methodological ways through which DFSS theory can be used, and allow each company to follow its methodological approach because each company is unique and has intrinsic characteristics.

2. Six Sigma Production

Since the movement that quality began a few decades ago, many improvement models were created, adapted and applied to processes over the years. Most of them are based on the steps introduced by W. Edwards Deming, the PDCA cycle (Plan, Run, Check, Act) which describes the basic logic process improvement based on data (Fioravanti, 2005).

Motorola developed the MAIC cycle (Measure, Analyze, Improve, Control) as an evolution of the PDCA cycle. Later, this cycle was adopted by the company G.E. which included an initial phase called the letter D in order to recognize the importance of defining a project, calling it the DMAIC (Define, Measure, Analyze, Improve, Control) (Fioravanti, 2005). The DMAIC method became the base of Six Sigma philosophy for business, it is fundamental to its success. It is a revolutionary methodology for the improvement of business processes, which gives improvements in quality and productivity gains due to the reduction of costs. It uses the application of statistical methods to business processes, to eliminate defects. There are several benefits such as operational efficiency increased, costs reduced, quality improved, and customer satisfaction and profitability both increased.

2.1 DFSS (Design for Six Sigma) Methodology

According to Treichler et al. (2002), DFSS is a culture change that occurred in the organization design and product development, from deterministic to probabilistic. People are trained to incorporate statistical analysis of failure modes in products and processes. The goal is to incorporate changes which eliminate design features with a statistical probability of failure within a predefined range of conditions and operating systems. According to Dias, (2015), the methodology or methodological tool, DFSS (which integrates DMADV cycle) is directed to:

• Create new products that motivate the purchase by customers in order to obtain higher profits;

• Detect and prevent the occurrence of failures before they occur in the product (prevent them from occurring during or after the production phase).

There are several tools that can be useful when related to the DFSS and DNP. Between the beginnings of the development creative design and creative solution, is expected that it should use some instrumental tools such as: Pugh analysis; DOE (Design of Experiment) and/or DFX (Design for Excellence). DOE is used to support the planning optimization, implementation and analysis of an experiment in order to obtain solutions to DNP problems. DFX is suitable to quality improvement during the production phase. It is expected the achievement of creative solutions by the creative design, for the respective problems of DNP projects (Dias, 2015). It is possible in the same problem of DNP, associate several tools such as tolerance design that sometimes is use in combination with DFSS and robust design; and the axiomatic design with robust design and both with DFSS.

2.2 SS vs. DFSS

The Design for Six Sigma, at first analyze, appears to be an extension of the Six Sigma methodology. It should be noted that this is not a reality. The DFSS and Six Sigma methodologies are independent, however, DFSS has many characteristics that make the Six Sigma methodology known worldwide. Having in account the differences between these two methods, it can be concluded that the DMAIC cycle is used in production processes and services that are in need of significant improvements in its sigma level performance. I can say that the DFSS is the planning of the SS, to which (SS) corresponds the DMAIC (production). First of all, it is important to understand which are the parts of the process that are underperforming and must need an improvement, for after applying Six Sigma in these specific parts, the performance in general, improve an satisfactorily way. The application of the DFSS is different. It is applied when is wanted to do a new process. So it is studied and designed (Design for Six Sigma) to start its activities having a Six Sigma level performance. (Dias, 2015).

All the tools that are applied in Six Sigma methodology can also be applied in DFSS methodology, but the opposite is not true, some tools are specific to the DFSS because they are applied specifically to the development of new products (Fioravanti, 2005). Figure 1 shows a diagram that explains the integration of Six Sigma methodology (improvement of product performance and process) and DFSS (design of new products and processes) based on the procedure for design selecting.

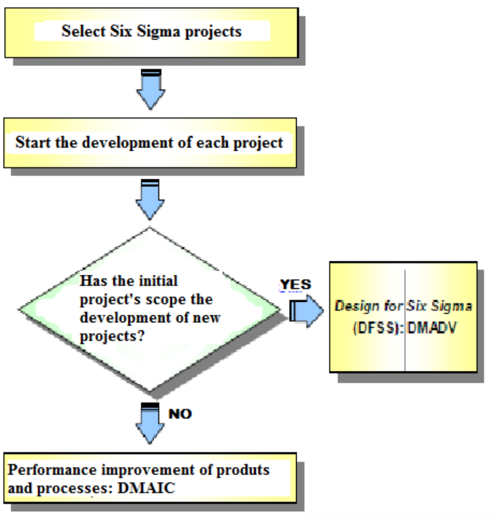

Fig. 1 This is an example of a figure caption Decision of the best methodology to use, Six Sigma (DMAIC) or DFSS (DMADV). Adapted from FioravantiI (2005).

The approach based on DFSS is suitable to the creation and development of new products, services and processes, not so much to the improvement of ones that already exist, taking this aspect and the curative nature of interventions linked to the SS methodology (Dias, 2015).

Sometimes the best solution isn't start over. Often improve the current situation can be necessary and the best option in financial terms. The development of a new product depends on a several factors like the stage of the current product life cycle, its competitive position in the market, its projection to the following years, etc. So, DFSS and Six Sigma are presented like complementary and independent methodologies (Werkema, 2002). On the other and, Treichler et al. (2002) are stringent in their affirmation that diverges from the above idea exposed by Werkema (2002), which Treichler quoted: “The DFSS is a much more effective way in financial terms of obtaining Six Sigma quality levels rather than trying to fix problems after the product finds it’s place in the market”.

As shown in Figure 2, it’s in the DFSS operating area that the costs associated to the correction of non-conformities are lower. However, these non-conformities are harder to detect, which is why it’s necessary to use several analytical tools, in order to anticipate potential anomalies (Dias, 2015).

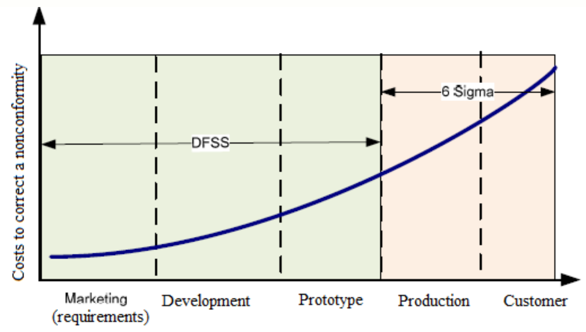

Fig. 2 Operating area of the DFSS and SS, concerning the product life cycle. Adapted from Dias (2015).

Concerning the present investigation focused on DNP innovative process, the most adequate tool to be used in the design phase is DFSS theory and its instrumental tools: the DMADV cycle and the ones that developed from this.

These new cycles, were born, in alternative to the DMADV, to answer the unique characteristics and special needs of each company, in a way that ensures the creation of an effective and efficient culture to the DNP (Dias, 2015).

3. Case Study

3.1 Company 1

The following case study, concerns to a company that will be designated from now on as enterprise 1 due to issues concerning confidentiality.

The enterprise 1 is a SME of the industrial maintenance sector. Works for other companies and provides electrical maintenance services, maintenance of rotating and static equipment. Usually do the replacement, repair or calibration, and especially in rotary do the conditioned maintenance because it has this valence. Concerning the DNA, the company mostly does continuous improvement actions of products that exist, so there is no substantial innovation.

It is a company with about 15 permanent employees and at the work peaks can reach 100. The correspondent in terms of time, to have 40 people working (100 floating employees and 15 permanent ones gives the equivalent of 40 working per day). Only when the company has about

30 or 40 people working permanently, it becomes possible to make a routine that allows applying the DFSS tool. The approximate turnover is about 3 million euros per year.

The enterprise 1 doesn't have implemented the Six Sigma program, but this program is known by it. It is periodically updated and is certificated by the standards ISO 9001, ISO 14001 and OHSAS (18001).

It doesn't have a quality department but has a responsible person in this area. It is common in SMEs not to have a specific department for quality. The system is structured from bottom to top, it cannot be done by the book (implemented from top to bottom), involving the participation of all employees in the implementation of operational and technical procedures. All the basic part of the quality structure is mounted from the participation of all people, therefore the person responsible for the quality, translates what people do in a procedure, so that there is uniformity, where the spirit of the people is evident. This happens in a later stage, when crossing other levels of procedures, in company's senior management or business management, people are prepared to receive training or awareness, because they participated in the bases of the system. Thus, it becomes easier to judge the introduction of a given system. One of the people interviewed, a board member of the business group, quoted: "When you want to apply something that was previously done to someone who has an education or more basic training, this only brings waste time for the person, rest or nap and isn't useful for nothing."

Enterprise 1 has used the DFSS tool and recognizes that it would be beneficial to use more this tool, although it is not possible to do in a permanently way. The major problem of the company, which is common to most Portuguese SMEs, is the reduced number of employees and the lack of technical qualifications, so it is difficult to make this implementation. In a theoretical and organizational point of view, the use of DFSS tool would be important to the companies, but as they are "crushed" by the market, they focus on meet established plans. Often quality programs are introduced in order to release the pressure imposed by customers. Sometimes, companies are required to present the security and environment procedures that must be in accordance with the large company for which they work, whether the operating place is or where large companies operate. There is a wide variety of mechanical equipment, because of that, the company is being restricted to implement DFSS tool.

In enterprise 1 there are situations where it's not necessary to use the DFSS tool like when there is a very specific contract to a particular project, with a specific thing or a simple project. There are two types of SMEs: the companies like enterprise 1 with intensive production and capital-intensive, which produce a large number of units. These companies can apply to DFSS tool, just do not have the technical ability to use the tool when the project has few dimension; and small but technology-based companies with highly qualified people, focused on project development, and these are the companies that are emerging too in Portugal. To implement DFSS system and to involve more qualified people, it's easier for a company like enterprise 1 that has manufacturing units, answer the needs of a large company like Autoeuropa, for example.

According to the interviewed the costs of using the DFSS tool in a management system should be considered as investments. That will result in efficiency and improving the quality of a production process. As in the area of quality, when it made the implementation of a system, it can first be seen as a cost, but when it's start to find what was the cost of production of a company before and after applying that system, it's found that the company that is organized according to this methodology (six sigma program) starts to produce better, cheaper and with deadlines, which is very important.

When there is a need for training, people take courses that have a short term, in which the person leaves the company, makes the course and is suitable in terms of knowledge to use DFSS tool property. Usually this kind of people must have good knowledge in the quality area as a whole, in order to use DFSS tool. Otherwise, the course will not be worth it. There're two main problems for the companies: one, is the lack of capacity of the managers, and two, the low-skilled people, therefore when there is no organization and people do not have training, companies do not work. First people must be sensibilized and only then can be trained.

Also, according to the interviewed, the DFSS tool forces the company to retain a client, and with this, the company knows that the project will bring profit, usually a margin of 5% or so. The profit on the work that was done is not very high, but can be certain in order to know exactly the margin. There are situations which because of the urgency to perform a job, the work is much better paid, so the margin is higher. The margin variability depends on the urgency of the delivery of the work or service (corresponding to shorter deadlines). The company over the years managed to get better, even lowering the value of the contract. This is possible with the observation, which is a very important factor when working with a large company, see the progress of work, see whether there are delays and try to find a way and tools to produce faster and at lower cost. This process of improvement could be made using the innovation, but this has never been done in the enterprise 1. A large volume (e.g. half a million), can give a margin of 2 to 3 percent to the company, which in the industrial maintenance area, which is very good.

As a conclusive note, after the interview, is concluded that the companies that provide services can be considered as production companies, as enterprise 1. They repetitively do a series of activities and jobs. To use the DFSS methodology tool, the first step is to see, within the company, which is identical and different in order to arrange like the methodology asks. The essential is the dimension. It is a concern if the company does not implement ways to work well, according with deadlines and being competitive in market. There were a several improvements over the years in this company, that have been implemented until now, but with these improvements, the margins can be "crushed" because often the large companies, year after year, when jobs are repeated, try to see if it can "squeeze" the kind of service that is done by the SMEs, reducing the cost, the value of the contract and see if they can do the same thing for less money. There are cases where the work that was done ten years ago, nowadays can be made by three quarters of the price. As margins decrease is necessary to look for other ways to overcome this situation, and the solution for a particular job is not the DFSS tool, it should look for another similar that best suits the type of service. As the large diversity of works that are made by the company, it must have a very accurate idea of the company's own value chain to be able to see in which situation it can use the DFSS tool.

4. Final Conclusions

It was possible to demonstrate that the application of DFSS, through its strongly structured methodology, achieves significant gains in terms of the quality of product optimization already in its development process, to avoid higher costs of further product modifications when it's already in a production phase and answering the consumer's needs (voice of costumer).

The enterprise analyzed in the case study uses, punctually, the DFSS tool in order to attend their customer's needs, which in most cases are big named companies that can have the Six Sigma program implemented. The fact that the DFSS and the Six Sigma methodologies are independent, however complementary, makes possible the punctual use of DFSS in some companies, like the one studied. Therefore the DFSS tool presents itself as a good way to help SMEs in order to make these capable of integrating themselves in client companies that present high standard project requirements.

In another point of view, it's possible to a company that uses DFSS in the DNP context, to substantially decrease the costs associated to the product, service or process life cycle, since that DFSS presents a preventive approach that looks for failure occurrence to prevent errors due to these failures. For this reason and for the complexity of some instrumental tools used and its connection, DFSS projects can be time-consuming and of higher risk compared to SS projects, which are contemplated in the production phase in course. This being the only disadvantage associated with the use of DFSS.

Lastly, it's possible to assert that the implementation of Six Sigma methodology is a benefit to some companies, although it's not affordable to most of Portuguese SMEs given that in Portugal, companies of high technological level and qualification, are increasing. The use of DFSS it's a good alternative to answer the high standard levels of potential clients.

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Evaluation of Sustainable Competitiveness through Innovation

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Abstract

Clients' continuous expectation increase and the need to be ahead of competitors, cause a huge pressure in companies and aggressiveness into markets. Due to this fact, companies' need to be in permanent change to gain competitiveness. One way to achieve this aim is through innovation. But the question is How? Where to innovate? Innovation at any cost? What kind of impacts should be expected? Is it possible to evaluate companies' innovation skills and stablish a relation with outcomes? This paper provides a model that contributes to competitive advantage creation through innovation integrating concerns about sustainability, based on the triple bottom line principles. Therefore, the model promote innovation preserving a balance between economic, social and environmental results. The model is based on 7 competitiveness drivers, which include all key factors of a company, and allow the evaluation of companies' resources to be innovative, taking into account requirements structured in 8 proficiency levels. Additionally, the model allow the evaluation of the companies' competitive advantage, considering innovation indicators, related to each competitiveness driver. This evaluation promotes another perspective of companies' innovation capability, as well as the identification of opportunities to improvements, concerning the areas where companies have lower scores regarding innovation resources and results. This model, in this perspective is an added value tool, once it allows a more focused approach about innovation priorities, taking into account that innovation cannot be just considered "product innovation" and the fact that there are a lot of other aspects in an organization that have influence on it.

Keywords: Strategic planning, Competitiveness, Sustainability, Innovation, Evaluation

1. Introduction

The constant need to be ahead, aiming to achieve competitive advantage, is the fundamental reason that drives companies to be innovative. With this purpose it is crucial to develop capabilities to foresee new business opportunities and to create market trends, which requires strategic vision, taking into account their resources' limitations and potentialities (McManus et al, 2007). This attitude demand the ability to explore alternative strategies and the talent to lead/ manage resources to new projects (Hamel & Valikangas, 2003). In such a context, it is vital to define appropriate strategies to face this challenges and to do so, companies should integrate innovation models into their strategic planning processes, allowing the evaluation of their current competitiveness and the appropriate definition of their business goals, operational targets and actions needed to achieve their objectives in a sustainable way.

2. Problem Statement

Nowadays companies are more exposed to market changes and more vulnerable to customers' demand and competitors' aggressiveness. This fact increase companies' pressure to survive and to avoid bankruptcy or insolvency. According to (Gittleson, 2012) *"The average lifespan of a company listed in the S&P 500 index of leading US companies has decreased by more than 50 years in the last*

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century, from 67 years in the 1920s to just 15 years today, according to Professor Richard Foster from Yale University, by 2020, more than three-quarters of the S&P 500 will be companies that we have not heard of yet. Also Fortune 500 has a similar view about this issue, (Perry, 2014) says that *"almost 88% of the companies from 1955 till 2014 have either gone bankrupt, merged, or still exist but have fallen from the top Fortune 500 companies."* Considering (Collins, 2009) *"Every institution, no matter how great, is vulnerable to decline. There is no law of nature that the most powerful will inevitably remain at the top. Anyone can fall and most eventually do"*.

Indeed there are a relevant number of cases that are evidences of this reality, namely big companies from different economic sectors that never imagine could fall into bankruptcy, like WorldCom (2001), Enron (2001), Arthur Andersen (2002), Parmalat (2003), Refco (2005), Delta Air Lines (2005), Lehman Brothers (2008), General Motors (2009), Blockbuster (2010), Kodak (2012), among others.

To reduce the risk of bankruptcy companies need to be prepared to face changes and to gain competitive advantage. Clayton (1997) stated that *"If you do what worked in the past, you will wake up one day and find that you've been passed by"*, and explained how innovation can be an advantage. Also in (Lendel & Varmus, 2011) perspective *"the companies try to ensure their competitiveness through innovation. To be in the company conducted effective work with innovation is necessary to adopt and implement an innovation strategy"*.

Following this line of thoughts, Drucker (1985) offered a systematic approach to the creative process by the introduction of the discipline of innovation and (Dibrell et al, 2011b) introduce the concept of innovativeness, which means that firms' emphasis their strategy on innovation.

On other hand, new concepts like sustainability arise and may be of interest to be considered in the design of alternative models. In fact, sustainability can be based on the triple Bottom Line (3BL) principle (Norman & Macdonald, 2004), and according to this researcher *"The idea behind the 3BL paradigm is that a corporation's ultimate success or health can and should be measured not just by the traditional financial bottom line, but also by its social/ethical and environmental performance"*. Following (Hubbard, 2009) *"The TBL adds social and environmental measures of performance to the economic measures typically used in most organization"*. It seems to make sense to use this principle to evaluate companies' performance (results).

Considering the above, the aim of this research was to design a model to support companies on their strategic evaluation process, taking into account their current competitiveness based on their capability to be innovative and their capacity to increase their performance, measured through economic, social and environmental results (sustainability).

3. Research Methodology

Therefore the research methodology applied was a deductive approach, once this method assume empirical approaches to validate hypothesis and assumptions. Beyond the literature review, which allowed the analysis of several strategic planning approaches and tools (e.g. PESTLE[3], Balanced Scorecard, LARG[4], among others), the most worldwide recognized evaluation models and international standards (e.g. EFQM[5], Shingo Prize, GRI and DJSI[6], IS0 9000 (series)[7], 14001[8], 22400[9], ISO 26000[10], ISO 45001[11], ITIL[12]); there were involved 18 experts to obtain feedback and validations about the model's components and

[3] PESTLE – Political, Economic, Social, Technological, Legal and Environmental analysis;
[4] LARG – Lean, Agile, Resilient and Green
[5] EFQM – European Foundation for Quality Management excel award
[6] GRI – Global Dow Jones Sustainability Index
[7] ISO 9000(series) – Quality management
8 ISO 14001 – Environment management
9 ISO 22400 - Automation systems and integration -- Key performance *indicators* (KPIs) for *manufacturing* operations management
10 ISO 26000 – Social responsibility
[11] ISO 45001 - Occupational health and safety
[12] ITIL - *Information Technology Infrastructure Library*

indicators, through questionnaires and workshops.

There was a concern to select experts according to appropriate profiles to assure their suitability to reach the research objectives. Therefore, four selection criteria were established, namely: Overall business experience and vision; Years of professional experience; Current role and professional career; and Specific skills related to the research filed. The pool of experts considered had an average age of 51 years old (minimum of 38 and maximum of 66 years) and more than 485 accumulated years of experience (minimum of 15 and maximum of 41 years), covering all critical business dimensions and relevant components pre-defined at the research scope, due to their careers in management, quality, monitoring, innovation, sustainability, manufacturing and logistics and in technology.

4. The Sustainable Competitiveness Evaluation model – innovation based

The present research enabled the design of a sustainable competitiveness evaluation model, based on innovation dimension. The model assume that companies should evaluate two components to be able to define more reliable strategic goals and targets to reinforce and achieve continuously competitive advantage, through innovation, in concrete:

- Their resources or ability to manage them, in order to be systematically innovative (focused on the company's innovation efficiency); and
- If they are an innovative company (focused on the company's innovation impact or results, which means their innovation effectiveness).

According to the above, and taking into account the "Innovation S – Curve" or the innovation lifecycle framework of (Dismukes et al, 2012) it is possible to establish a relation between innovation resources management and innovation performance (Figure 1).

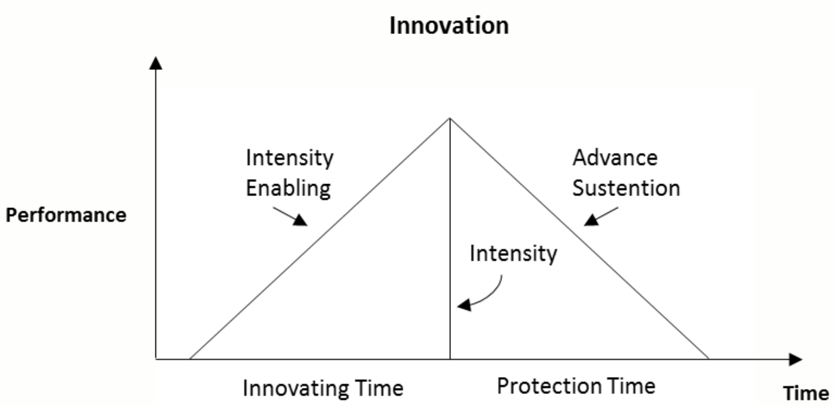

Figure 1 – Innovation Triangle

The Innovation Triangle assume two parameters that define innovation dimension, which depend on time and have impact on performance (innovation indicators allow to express innovation results in terms of economic, social and environmental values), namely:

- Intensity Enabling – which measures the resources ability to be intensively innovative, which means that a higher performance level stated is achieved faster. Thus, Innovating Time is shorter when this parameter has high values.
- Advance Sustention – which measures the resources ability to maintain longer this innovation advantage. Thus, better this parameter the longer is the Protection Time.

Considering this assumptions, we conclude that if a company has a short innovation time and a long protection time and is achieving high innovation results (performance), then the company can be considered has having sustainable competitiveness. If compared with a competitor, acting in the same economic sector, and if its evaluation results reveal a better score than its competitor, then the company have a competitiveness advantage in terms of innovation.

Anyway, the question that should be answered now is: How can innovation resources management be measured, as well as what kind of innovation indicators should be used?

Considering the analysis of several evaluation models and strategic approaches, we define seven competitiveness drivers (Table 1), which are the foundations of the Sustainable Competitiveness Evaluation model based on innovation.

Table 1 – The 7 competitiveness Drivers of the sustainable competitiveness evaluation model based on innovation, considering a comparison analysis with other models and approaches

<table>
<tr><th>Criteria of EFQM model</th><th>Principles of Shingo Prize model</th><th>Competitiveness Drivers</th><th>Balanced Scorecard Perspectives</th><th>PESTLE</th></tr>
<tr><td>Leadership</td><td>Culture Enablers
Leadership & Ethics
Enterprise Culture
Enterprise Thinking
Consistent Lean Policy Deployment</td><td>Corporate Behavior</td><td>Learning and Growth</td><td>Political
Legal</td></tr>
<tr><td>Strategy
Customer Results
Society Results</td><td>Quality
Delivery
Cost
Competitive Impact</td><td>Business Proposition</td><td>Customer</td><td rowspan="2">Economic</td></tr>
<tr><td>Business Results</td><td>Business Results
Financial Impact</td><td>Financial Stability</td><td>Financial</td></tr>
<tr><td>People
Partnerships & Resources
People Results</td><td>People Deployment</td><td>Organization Wellbeing</td><td>Learning and Growth</td><td>Social</td></tr>
<tr><td rowspan="3">Processes, Products & Services
Partnerships & Resources</td><td rowspan="3">Continuous Process Improvement
Lean Ideas
Value Stream & Support Processes</td><td>Operational Leanness</td><td rowspan="3">Internal Business Processes</td><td rowspan="3">Technical
Environmental</td></tr>
<tr><td>Technological Alignment</td></tr>
<tr><td>Facilities Suitability</td></tr>
</table>

Once the definition of the seven competitiveness drivers and after more detailed analysis, reflections and workshops with experts, 14 competitiveness elements were established, as well as 24 evaluation criteria (sources of enhancement) – Table 2.

Table 2 – Competitiveness elements, sources of enhancement and leverage factors by each competitiveness driver of the Sustainable Competitiveness Evaluation Model based on innovation

Corporate Behavior

Competitiveness elements	Sources of enhancement	**Impacts of high innovation** (Leverage Factors)
Culture and leadership	Innovative Organization	Increase of Organizational alignment with innovation Share of innovation commitment Creation of an ownership environment (employees feel like part of the team)
	Innovative Leadership	Auto-creativity deployment Talent maximization Increase of opportunity to generate differentiation
	Society commitment	Trustworthiness increase Increased recognition by the adoption of differentiated social initiatives
Management and knowledge	Strategic Vision	Anticipation in the face of competition Business perpetuity Leverage of strategic partnerships
	Quality and Environment commitment	Continuous innovation improvement Reduction of environmental impacts Increased recognition and visibility among stakeholders
	Governance and empowerment	Creation of idea-generating environments Increased accountability for innovation and self-motivation Increased probability of successful innovation
	Wisdom deployment	Information exploitation improvement and increased capacity to implement competitive advantage generating strategies Increased idea sharing dynamics and the capacity to create innovation Maximizing the use of available / generated knowledge
	Shareholders and strategic partners engagement	Greater assurance of continued investments Enlargement and increased confidence and motivation of the research partner's network Research cost sharing and increased exchange of know-how

Business Proposition

Competitiveness elements	Sources of enhancement	**Impacts of high innovation** (Leverage Factors)
Customer relationship	Trends and needs creation	Creation of market appetence for new products / services Reduced risk of inadequate value proposals Increased market share and competitive leadership (time to market achievement)
	Customer and society recognition	Increased recognition as an entity that generates innovation Increased brand and product loyalty
Commercial focus	Marketing and salesforce engagement	Increased confidence and relationship with customers Increased sales Reduced marketing and sales efforts due to the differentiation of products / services

Financial Stability

Competitiveness elements	Sources of enhancement	**Impacts of high innovation** (Leverage Factors)
Assets management	Investments management	Continuous patrimony valorization Financial and business risk dispersion Return on investements maximization
Financial solidity	Financing ability	Increased ability to invest and to grow Increased bargaining power

Organization Wellbeing

Competitiveness elements	Sources of enhancement	**Impacts of high innovation** (Leverage Factors)
Human resources management	**Talent research and retention**	Increased ability to attract and retain talent Talent allocation improvement according to innovation needs Increased capacity to offer exciting challenges
	Entrepreneurship	Creation of intellectual assets Transforming ideas into business Increased personal satisfaction and self-esteem
Employee development and safety	**Talent preservation and valorization**	Incorporation of trends and best innovation practices Reduced innovation cycle time Increased self-learning and enthusiasm for innovation
Respect and Recognition	**Corporate commitment to employees**	Continuous employee engagement to innovation Increased complicity and reinforcement of team spirit Consolidation of relationships between employees and top management

Operational Leanness

Competitiveness elements	Sources of enhancement	**Impacts of high innovation** (Leverage Factors)
Supply chain management	**Strategic Sourcing and procurement**	Stimulus to the creation of more innovative raw materials Gains by economies of scale and by reducing processing costs Research cost sharing
	Operational logistic innovation	Incorporation of transport, handling and storage innovative solutions Increase of information integration and lead time reduction Decrease of logistic costs
Development, manufacturing and service delivery	**New product/ service research, design and deployment**	Provision of innovative products and services Placing of competitive prices Increased awareness
	Methods, time and tools innovation	Increased process efficiency and reduced operating costs Lead-time and time-to-market reduction Increase of zero-defects

Technological Alignment

Competitiveness elements	Sources of enhancement	**Impacts of high innovation** (Leverage Factors)
ICT solutions	**ICT development engagement**	Active participation in research and development in ICT Incorporating innovative valences in ICT Reinforcement of the positioning in the partners network
ICT Services	**ICT services innovation**	Increased capacity to generate innovation in ICT services Encouraging innovation and entrepreneurship by way of example

Facilities Suitability

Competitiveness elements	Sources of enhancement	**Impacts of high innovation** (Leverage Factors)
Facilities management	**Facilities and security innovation**	Increased recognition as a sophisticated and innovative Organization Improvement of ergonomic issues Introduction of environmental and safety solutions

Thus, the model allow the evaluation of a company's innovation competitiveness by analyzing the level of compliance and evidences of the ability to comply with each of the requirements that express each leverage factor for each evaluation criteria (Table 2).

Even so, we still evaluating resources. In fact we just are capable to evaluate the company's ability to innovate (how the company manage their means to reduce innovation time and to enlarge innovation protection time). So, to complete de evaluation model, the innovation performance measures should also be defined. With this purpose, among a wide range of indicators applicable, we selected 18 indicators to be part of the model (Table 3), which should be measured annually.

Table 3 – Innovation indicators of the Sustainable Competitiveness Evaluation Model based on innovation

Corporate Behavior (4)

Impact Indicator	Evaluation Purpose (what is the company's …)	Calculation (metrics)	Sustainability dimensions			R/I
			Economic	Social	Environmental	
Environmental index	Commitment to global warming and climate change reduction	(Total of gas emission x total of water consumption x total of energy consumption x total solid waste produced)/ GVA			X	I
Patents and trademark index	Innovation effectiveness	0,8 x nº of patents approved + 0,2 x nº of trademarks registered	X			I
Average innovation cycle time	Innovation efficiency	$\sum^{n}_{i}$ time since idea till launch of the new product or service$_i$/ nº of new products or services launched	X			I
Number of scientific publications	Relevancy to innovative and scientific knowledge (innovation recognition)	Nº of scientific articles published in recognized scientific journals (ex.: ISI)	X	X		I

Business Proposition (2)

Impact Indicator	Evaluation Purpose	Calculation	Economic	Social	Environmental	R/I
Sales of new products (and services) on total of sales	Capacity to convert innovation into business	(Sales of new products and new services/ total of sales) x 100	X	X	X	I
Sales of green products (and services) on total of sales	Ability to convert environmental commitment into business and introduce green solutions into the value chain	(Sales of green products and green services/ total of sales) x 100	X		X	I

Financial Stability (2)

Impact Indicator	Evaluation Purpose	Calculation	Economic	Social	Environmental	R/I
EBITDA profit margin (profitability)	Ability to generate profit, through higher prices based on quality advantage, perception or branding; or through lower product costs due to production efficiency or economies of scale	(EBITDA/ Gross revenue) x 100	X			I
RoPDE (Return on product development expense)	Innovation effectiveness (ability to generate earnings by new products or services)	(Gross Margin – PDE)/ PDE x 100	X	X	X	I

Organizational Wellbeing (3)						
High qualified employee rate	Commitment to excel, continuous improvement, research and innovation	(Nº of employees with doctoral or master degree/ total nº of employees) x 100		X		I
Training costs per employee	Commitment to continuous training and development of employees' skills to promote improvements and innovation	Total training cost/ total nº of employees		X		R/I
Carbon footprint per employee	Capacity to reduce carbon emission	Total carbon emission/ total nº of employees			X	I
Operational Leanness (3)						
OEE (Overall Equipment Effectiveness)	Operational productivity	Availability x Performance x Quality	X			I
% of recycled material used as raw material input	Commitment to green supply chain	(Nº of recycled units of raw material/ total units of raw material used) x 100			X	I
Non conformity rate	Operational reliability	(Nº of defect units/ total units produced) x 100	X			R/I
Technological Alignment (2)						
ICT investment rate	Commitment to ICT up-grading and overall performance increase	(ICT investment amount/ (total investment amount – direct innovation investment)) x 100	X			I
Number of systems integrated with other company systems	Ability to integrate ICT systems in its value chain	(% ICT suppliers integration + % ICT customers integration)/ 2	X	X	X	R/I
Facilities Suitability (2)						
Ergonomic and health costs rate	Commitment to employee health and capability to avoid occupational diseases	((compensation for injury, mutilation or deformity + absenteeism costs due to diseases)/ total personnel costs) x100	X	X		R/I
Space productivity	Facilities efficiency	Gross revenue/ facility's square foot	X		X	I

5. Conclusions

The validation process handled with the experts of this research allowed to conclude that the sustainable competitiveness evaluation model - based on innovation, seems to be a value added approach. In fact, they had a unanimous opinion about the importance of the model and all assumed that it could be a helpful tool for managers to identify in what fields of innovation the company need to improve, as well as to support the definition of actions that should be implemented to drive the company to higher levels of sustained competitive advantage. In spite of the expert's opinion, the suitability of the model should be validated through its application on a real business context, through the development of cases studies.

Regarding the model's improvement, other issues could be taken into account for further research and to answer to additional aspects, namely product-related sustainability factors, such as for example at Business Proposition sales of green products should be also "social"? at Financial Stability could be another aspect producing more intelligent or more simple products? at Organization Wellbeing the ability for problem solving and to people change themselves should be incorporated? Carbon footprint per employee should be called at Operational Leanness, too? Technological Alignment should also check the consequences of new product (medium term, long term)? Facility Suitability should also contain the investment for suitable facilities for an effective innovation process, or this is covered by Financial Stability?

It is possible to conclude that, although the developed model achieved which at this stage can be assumed as a benefit for companies as a tool to support the process of increasing their competitive advantage, there still room for improvements.

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Effective New Product Development by Using Inventive Problem Solving Tools in Systematic Innovation Method

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Abstract

The research addresses a real-world problem about handicaps of plastic bottles when the hot liquid is filled in the plastic bottle and cooling with the closed cap. Idea screening and concept design are the core parts of the New Product Development. The paper provides the alternative approach for these core stages by using Systematic Innovation methods. The principles and concepts are discussed based on Systematic Innovation methodologies. The method has been already applied several practical applications and gives the guidelines to be adapted into new product development innovatively. The design of the new bottle system demonstrates effectiveness and significance by applying the systematic innovation method for generating innovative idea.

Keywords: Bottle design, New product development, Product manufacturing, Systematic innovation, TRIZ, TIPS

1. Introduction

A PET (Poly-Ethylene Terephthalate) bottle is reusable and reduces amount of waste that goes into landfills. PET was commercially introduced by Coca-Cola in 1979 as their soft drink bottles which were promoted as unbreakable form of bottles. Eventually, it has been also used by all other beverage companies for their beverages. Although a glass bottle is most reusable, it uses heaviest materials commercially. Regarding the environmental perspective, glass is best choice for companies because they want to be eco-friendly. On the other hand, PET materials would be a better option due to its lightness of weight that could minimize shipping loads in terms of operations and manufacturing factors. Although typical plastic bottles cannot be reused in the same way as glass bottles can, the material composition makes possible to dump into landfills and allows to be reused as cheaper recycled plastic products. As it mentioned, the main reason to choose PET bottles is the weight difference between them. A glass bottle weighs around 6000 grams per a liter but a plastic bottle weighs only 33 grams per a liter (Isaac, 2012). This weight difference gives huge impacts for transportation of beverage products in the view point of logistics costs.

Recently, one of startup companies for beverages in Philippines has been using a plastic (PET) bottle for their packaging. Although this material is cheap and light, there are some problem for a hot (temperature) beverage packaging:

- Hot tea is poured directly in the bottle.
- Present design evolved through continuous changes in consultation with the manufacturer.
- Present design dents on the top portion of the bottle giving it unaesthetic appearance.
- Bottle cost is half the cost of the product.
- The cost of a mold for new bottle is around 67K USD in Philippines.

Because of the above reasons, the bottle design had been improved and a new bottle has been developed for pouring of the hot liquid into the bottle. The company had used the different design of the bottle in the past (Foodmarks, 2013) and it has been modified (Bayani, 2014). Both bottles (new and old designed) has been used for beverage packaging but the problems of hot liquid packaging are still remained. In addition, the company could not change the design frequently because the molding cost for new design is expensive. Even though, the company has tried to improve the design (Figure 1), denting the bottle is still one of the major problems. This project is targeted to deliver another new design of the plastic bottle which compromises the denting problem.

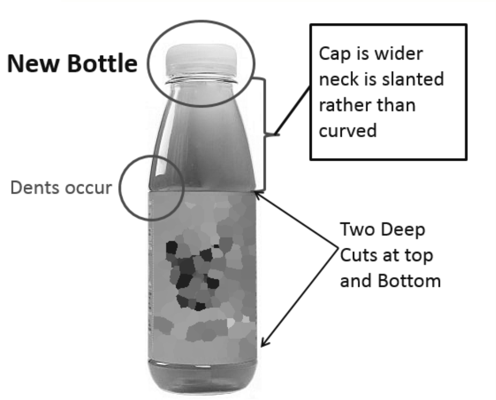

Fig 1. Current improved plastic bottle

New Product Development (NPD) is the complete process of bringing a new product into the market. Idea Screening and Concept Development in the NPD stage are the core parts (Koen, 2007; Ulrich and Eppinger, 2004). On the other hand, Systematic Innovation (Terninko, 1998) is a structured process and the set of practical tools to provide the guidelines for idea generations. It could be applied to create (or improve) products, process or services that delivers the new values to customers. Systematic Innovation tools (TRIZ) have been widely used for technical breakthrough and system improvements (Petkovic, 2013). The knowledge search based on the patents has been adapted for the innovative product design but it has not been targeted for wider range of new future product planning (Li, 2013). The systematic innovation contains the sets of the innovative problems solving tools (TRIZ) including the patent based knowledge search with the technology evolution patterns which could be adapted not only into wider range of the new product planning but also into the specific targeted product design to solve the current problems by technical breakthrough during the product development phase (Chen, 2009 and Howard, 2011).

The systematic innovation method suggests three general steps; Problem Identification is the step to identify the core problem and it is similar with the value identification in Lean Thinking (Womack and Jones, 1996). ENV model in OTSM-TRIZ (Mirakyan, 2009 and Khomenko, 2010) and RCA (Root Cause Analysis) are typical inventive problem solving (TRIZ) tools during Problem Identification step. Second step, most of TRIZ tools such as 40 inventive principles, Substance-Field model with 76 Standards (Domb, 2003) and ARIZ (Altshuller, 1989) are applied in Problems Solving step. Selection of the candidate solution and actual implementation is the last step as Concept Design Evolution step (Figure 2).

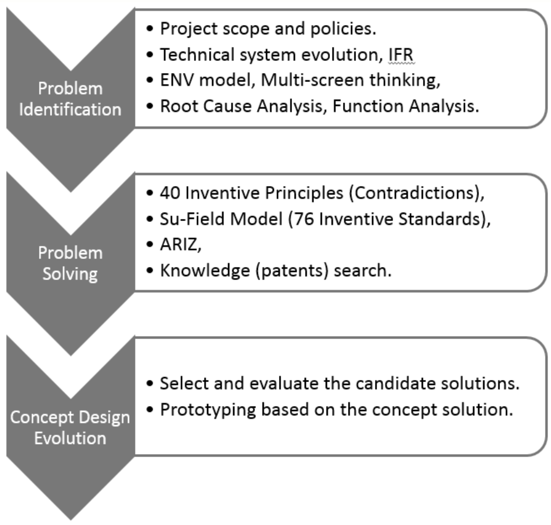

Fig 2. General process of the systematic innovation method

The systematic innovation method could be the recursive process and it is also a set of continuous evolving tools that will improve ability to solve the problems. TRIZ (TIPS; Theory of Inventive Problem Solving) is the most powerful tool set for systematic innovation (Domb, 1999 and Grace, 2001). Recently, the inventive problem solving techniques (TRIZ) are applied in management area (Jafari, 2013 and Lin, 2011) but the usage of TRIZ tools have been very limited. Most using TRIZ tool is 40 Inventive Principles which is relatively simple to use but the systematic innovation approach requires the combination of appropriate tools for each step. The tools should be applied on the right spot and it is hard to generate the practical new idea if the tools are applied independently without any sequence of the systematic innovation process. ARIZ (Algorithm for Inventive Problem Solving) provides the sequence (or process) of usage for the inventive problem solving tools (TRIZ). Even though ARIZ provides the most powerful framework to properly use TRIZ tools (Bukhman, 2012), it is rarely used for solving the problems (less than 10 percent) because of difficulties and complexity of this problem solving algorithm (Ilevbare, 2013). The sequence of the systematic innovation method (Figure 2) is the simplified process that helps to use the inventive problem solving tools (TRIZ) effectively.

In this paper, the design of the new bottle system as a product development example illustrates the systematic innovation application for getting innovative concept design idea. It also demonstrates the practical application to design the new products to overcome the problems which appear in a current product. Even though, actual development of the product has not been completed in this paper, the paper gives the guideline of New Product Development (NPD) by adapting the systematic innovation and good practices for developing the critical thinking skills even for non-engineering majored people.

2. New Product Development Based on Systematic Innovations

Systematic Innovation process (Terninko, 1998) contains the sequence (Figure 2) to provide the guidelines for using the appropriate inventive problem solving tools (TRIZ). In this research, the tools of the systematic innovation method in this particular research are as follows:

. *Problem Identification:*
- ENV Model*
- Function Analysis
- Root Cause Analysis

. *Problem Solving:*
- 40 Inventive Principles
- Substance-Field Model**

. *Concept Design Evolution:*
- Prototyping (design drawing only)

*) OTSM-TRIZ created by Khomenko (2010),
**) Enhanced Su-Field model created by Kim (2011)

The tool set (mostly part of TRIZ) for the systematic innovation method is targeted to support anyone who wants to create (or improve) products, process or services that deliver new value to customers. It is designed for improving the ability to solve the problems as out-of-box thinking. As it mentioned, TRIZ is the most common tool in the systematic innovation method (Rantanen, and Domb, 2002). Regarding this project, Root Cause Analysis and Function Analysis which both are the most popular TRIZ tools are applied in Problem Identification step. 40 Inventive Principles and the substance-field model with 76 Inventive Standards (Mao, 2007 and Terninko, 2000) are used in Problem Solving step even though these are old and conceptualized by Genrich Altshuller (1989, 1996, 1997,1999) who is the founding father of TRIZ.

2.1 Problem Identification

The sequence of Problem Identification is (1) ENV model (for the problem description), (2) Function Analysis, (3) Root Cause Analysis and (4) ENV model (for the solution descriptions). To analyze the problem more clearly, transforming the current problem to ENV model is a starter. ENV (Element-Name-Value) model describes the problem as Elements, the feature Name of the elements and Value of the feature. ENV model is the core part of OTSM-TRIZ (General Theory of Powerful Thinking) which has been created by Nikolai Khomenko (2010). OTSM is a Russian acronym which describes the next evolution of the classical TRIZ (Khomenko, 2010). ENV model helps to formulate the problem which makes it easy to adapt the classical TRIZ tools and allow to using various knowledge (Mirakyan and et. al., 2009). The problem of the current bottle is denting which means that the shape of the bottle is changed. This problem could be described by ENV model as follow:

Problems: The shape (volume) of the bottle is decreased;
. Element: Plastic bottle,
. Name of Feature: shape (volume of bottle),
. Value: decrease.

Both Function Analysis (also called Function Model) and Root Cause Analysis (RCA) could be the next procedure after ENV model and Function Analysis is applied before RCA for this time. Function model is the diagram that describe the system with functions and components (or elements). It is originally developed in systems engineering but it has been widely used as the TRIZ tool to describe the system. Bottle system instead of the bottle itself is considered for the function analysis. In the view point of the system, the bottle is not only elements to make the system (Figure 3) and there are more elements to build up the bottle system.

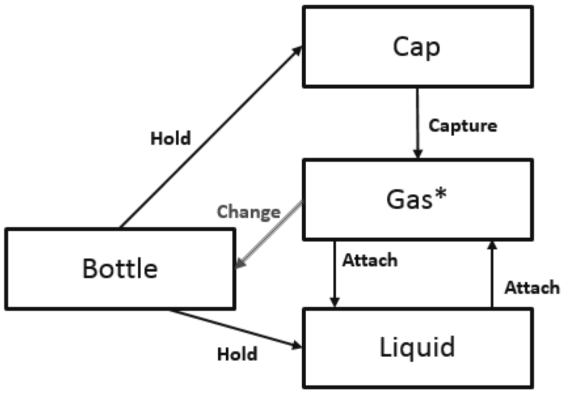

Fig 3. Function model of the bottle system

The function model (see Figure 3) reveals which element is the actual problem. According to Ideal Gas Law (Halliday and et. al., 2010), the volume of gas changed by the temperature. Since the beverage is relatively hot (around 80 Celsius degree) and it affects the volume of the air inside of the bottle when the bottle is sealed and naturally cooling down around 28 degree. Basically, the plastic bottle is not strong enough to sustain the volume changes of the air during naturally cooling the beverages.

RCA (Root Cause Analysis) is targeted to find the core problem from the original problem and expanding the RCA would reveal hidden problems.

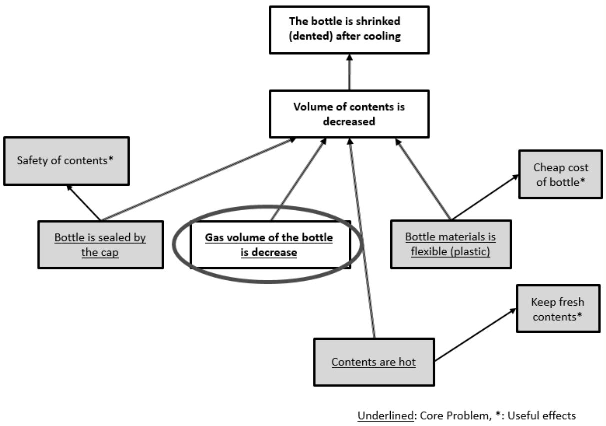

Fig 4. Root Cause Analysis

Even though, there are several root causes (underlined contents) on RCA (Figure 4), one root cause which is about the volume of gas in the bottle could be addressed as the core problem because other causes have the useful effects and their own purposes with the reasons.

Based on the function analysis (or function model) and RCA (Root Cause Analysis), the problem could be defined based on ENV model for describing the potential solution of the problem. ENV model provides the system relationships by using its capability to change the value (V) of one (or more) features (N; Name of feature) of the element (E) that changes it from Object to the desired Product (Khomenko, 2010). According to ENV model, the formulated statements of discomfort are identified from What-I-Want (WIW) stage. In this case, the object of the system is the plastic bottle and the element that affects the current object is the air in the bottle after cooling (see Figure 5).

Element	Name of Feature	Value of Feature	
		Current	Desired
Air (in the bottle)	Volume	< a (after cooling)	> a (after cooling)

Fig 5. ENV model for the solution

From WIW (problem) stage, the air should be kept as the certain amount of volume (a) after cooling down which means the temperature changes from 80 degree to 28 degree. The procedure to transform from WIW (problem) to ENV model gives the different view of the problems. Regarding this project, the problem has been changed to gas (or air) in the bottle instead of bottle problem.

2.2 Problem Solving by Inventive Principles

TRIZ provides the sets of 40 inventive principles and 39 system features. The system that has the technical contradiction could be clarified based on the feature for improve and the feature for remove within a set of system features (Altshuller, 1997). Originally, Altshuller reviewed patents in order to find out what kind of contradictions were resolved or dissolved by benchmarking the patents that had been achieved. Regarding this project, the contradiction matrix is applied as the parameter to improve and amount of substance as undesired result. The contradiction of the system is that the gas in the bottle is shrinking (i.e., volume is decreased) after the liquid is sealed in high temperature but the bottle is not strong enough to keep the same shape of the bottle. If the density of air is heavier, the bottle is dent and it means that the bottle is not strong enough to keep the shape before and after cooling down. The technical parameters and the recommendations from the contradiction matrix (Altshuller, 1997) are as follows:

Improving Feature:
Volume of stationary object (#8)
Worsening Features:
Strength (#14)
Responding Inventive Principles:
No. 9: Preliminary anti-action,
No. 14: Spherical shapes,
No. 17: Moving to another dimension,
No. 15: Dynamism,

The Inventive Principle number 9 is chosen to remove the harmful effects and incorporate the current bottle to develop new types of bottle system.

3. Concept Design of Bottle System

Based on Inventive Principle #9 from the previous session, several idea of concept design could be proposed. One design idea would be the modification or re-design of the bottle for preliminary anti-action (filling more gas before sealing the bottle). But, again, the design change of a bottle is very expensive and it is equally hard to apply the rapid prototyping approach. Instead of modifying a bottle, other elements could be considered for the preliminary anti-action. This situation could be described as the substance-field (Su-Field) model. The new type of the substance-field model without using the inventive standards is applied for this project. Even though the original substance-field model with Inventive Standards (76 Standard Solutions) is well defined and organized (Rantanen and Domb, 2002), it is still difficult to learn and complicated even for TRIZ specialists. More importantly, the 76 Inventive Standards are not intuitive (Soderlin, 2003). Enhanced Su-Field model provides the intuitive concept solution instantly once the problem is described by the proper notation (Kim, 2011). Users could deploy candidate solutions based on the enhanced su-field models without knowing full knowledge of 76 Inventive Standards. Object (S1) is the plastic bottle and Tool (S2) is the gas in the bottle. According to the enhanced Su-Field Model, it is *Problem Type-2* (Kim, 2011) that contains the harmful action and the candidate solution is basically removing the harmful function:

$$2/S/F\{/0\} \rightarrow \begin{cases} 2/S^*/F, & S^* = S^+ \; or \; S' \\ 2/S/F,^+ & \\ 2/S/F/a, & 0 < a < 1 \end{cases} \tag{1}$$

Even the above formula (1) shows the concept solution by adding a new substance ($S^*=S^+$) or modifying the substance ($S^*=S'$), but possible solutions are not limited. Actually, the candidate attribute of substance for Type-2 solution could be:

$S^*=\{S^*: S', S^+, S^2, S^\infty, S^n\}$.

The final recommendation of the concept solution for the enhanced new bottle design is:

$$2/S/F\{/0\} \rightarrow 2/S^+/F \tag{2}$$

where S^+ which indicates that the substance that added for preventing the distortion of a bottle. The additional substance for the solution is a modified cap to seal a bottle. The concept solution is modifying the cap which is an element of the bottle system, instead of changing the bottle by itself. The final recommendation, as demonstrated in Figure 6, is to come up with the new cap that has the elastic film (same materials as the cap but made it thinner) inside to capture more air when the bottle is sealed in hot temperature. Once beverage is cooling down, the elastic film is moved to fill the gap of volume decreasing in the bottle. It is noted that the air inside of the cap do not need to be vacuumed and it does not be required to have any specific gases because of Idle Gas Law (Halliday and et. al., 2010) which could be applied for any gases in the world. The mechanism for working in the cap only depends on the volume reduction by changing the temperatures from 80 Celsius degree to the room temperature (around 28 Celsius degree in Philippines). The air inside the cap reduces around 14 percent when the temperature is changed from 80 degree to 28 degree.

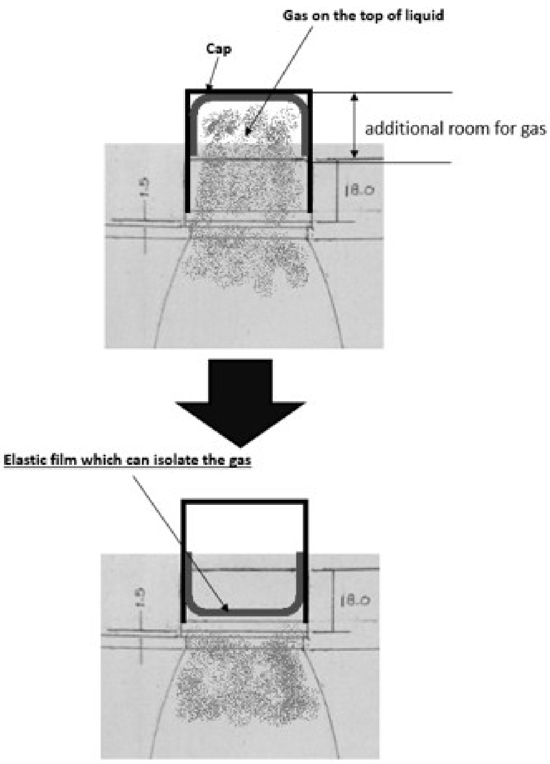

Fig 6. Prototype design of the new cap on the bottle

4. Conclusions

Systematic Innovation could be widely applied in the various area such as environmental engineering (Kim, 2013), helipad construction of the military airport (Cruz and et. al., 2013). It also has been partially applied in the high-tech industry problems, especially targeted for the institutive user experience design (Kim, 2010 and 2012). The major target of this project is demonstrating the new concept of product development sequences based on Systematic Innovations. The pattern of Systematic Innovation approach could be expanded to other industries on the top of the various cases mentioned above even though the research is dedicated with new product development. It is the good study case that gives the guidelines for whom wants to create the new things innovatively. As it mentioned, this research has been only targeted to develop the concept design and an actual product is not covered at this moment. The consumer 3D printing technology has been evolved rapidly (Kim, 2016) and making a proto-type of a new cap by using a 3D printer could be considered as the part of future research.

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Integrating Innovation and Technology: A Case Study

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Abstract

This paper explores a successful case of a product-service system (PSS). To meet the requirements of the client's needs and the existence of many technologies, business models and innovations involved in its conception and development, a conceptual framework of the ideation process is purposed to explain how the company met the requirements of such technical complexity, adding value to customers, stakeholders, and the company itself. Cases found in the development and implementation phase of the PSS displays the correspondence between the proposed framework and the case study. Furthermore, a relationship between creativity and systems' architecture is explored.

Keywords: Open innovation, Creativity, Product service systems

1. Introduction

Creativity has been defined in different ways in cognitive sciences' literature (e.g., Amabile 1996, Csikszentmihalyi 1996, Sternberg 1999, and Weisberg 2006). We see it as the ability to produce a product or a service, by a company, being both novel and appropriate for the market and in some extent, generate an innovation. The process of innovation in organizations is now a well-understood concept backed up by an extant and well-established literature (e.g. Crossan and Apaydin 2010, Tidd and Bessant 2009). Nevertheless, the fact is that the concept of innovation associated with creativity in companies is not so explored (DeGraff and Lawrence 2002) and worth of being further investigated. This fact is also absent in some of the relevant literature (Mont 2002, Brady et al. 2005, Morelli 2006, Vasantha et al. 2012) concerning "Product-Service Systems" (PSS).

In companies, a distinction between creativity and innovation is normally made (Amabile 1996, Davila et al. 2006). The term innovation is more frequently used, instead of the term creativity, to refer to the entire process by which new ideas are created and converted into original and useful products and/or services. On the other hand, creativity is recognized as a necessary building block to trigger new ideas, concepts and approaches to deal with existent or emergent problems, normally characterized by the efficient and aligned management of large amounts of creativity (DeGraff and Lawrence 2002) - creativity and innovation should be balanced to introduce value capture to the company. We also sustain that creativity is the building block of all innovations at companies nowadays.

Being much more than a simple product or service, Via Verde can be labelled a PSS. A PSS is regarded as a system of products/services with different technologies, business issues, equipment, interfaces, networks, organizations, and individuals that is designed to be competitive and satisfy customers' needs (see Oksana 2002, Morelli 2006, Vasantha et al. 2012). The above-mentioned domains of knowledge can be integrated (Howard et al. 2008), and in the authors' opinion, to explain the basic creative ideas behind any kind of innovation (Kelley and Littman 2004). One should consider, in general, the intersection between engineering design domains and cognitive psychology issues. Engineering design deals, for example, with the creative processes of innovation, such as the case of innovative PSSs, while cognitive psychology studies the process of creativity. The complexity of a dual cognitive-engineering perspective is normally difficult to explain without a strong conceptual background that supports it. With the purpose of understanding the impact of creativity in the innovation of a PSS, the authors have developed a descriptive framework of the ideation process (Author et al. 2014), partly based on existing models from both fields (such as Hatchuel and Weil 2003, Hsiao and Chou 2004, Ogle 2007, Stefik and Stefik 2004, Lawer and Yazdani 1991).

The framework addresses the issue of modelling the ideation, representing the interface of cognitive psychology and engineering design. Three domains – inspiration, decomposition and integration – and three spaces – problem-space, idea-space and concept-space are described as elements of the framework. The iterative flow of the engineering design process passes through these domains in a semi-controlled way, through a sequence of process loops in – and between the spaces. This framework is proposed to describe the ideation process of Via Verde's toll collection system. As so, the main objective of this study is to make a correspondence between the proposed framework and a practical use case. Moreover, we intend to answer to the following two research questions:

1. Can we use a conceptual framework to explain an empirical creative outcome such as the case of "Via Verde" system?

2. What is the nature of a possible relationship between creativity and systems' architecture?

After the literature review and background on the proposed framework and related issues to product/service architecture, we will present the methodology of this study. Then, empirical findings of the case are presented. After, the discussion's section covers the correspondence between the ideation framework and the PSS. Conclusions are drawn at the end of this article. This document is a template for Microsoft Word versions 2000 or later. If you are reading an html version of this document, please save it as a Word file so that you can use it to prepare your manuscript.

2. Literature Review

Idea generation is the creative process of generating, designing, and communicating new ideas (Jonson 2005). It comprises all stages of a product-service life cycle, being relevant to this study the initial or, sometimes called, fuzzy front-end (FFE) phase of an innovative design process. The literature review of creativity and ideation in the front-end phase of design has already been underpinned by the authors (Marques et al. 2014) and a descriptive framework of ideation has already been established and validated (Marques et al. 2014, Marques, 2016).

The literature concerning practices in design and cognition is recent and reflects the work of how a designer achieved the best solutions for problem-solving based on synthesis focusing on the solution to a given problem. The design method relies on the identification of a need, conceptualization, feasibility analyses, and production and testing and its success of is dependent on the competences of each designer, his/her personal creativity, three-dimensional visualization, and the ability to present the ideas in sketches. Also, design frameworks are basically classified into two classes: prescriptive frameworks and descriptive frameworks. The prescriptive frameworks tend to take a broader view of the design process, while descriptive frameworks bring into consideration the actions and activities developed during the design process. The original solution passes through a process of analyses, evaluation, refinement, patching and repair, and development, being a heuristic process. In the last ten years, some relevant articles have been published in engineering design research and in the present article, one has only identified and focused on relevant work for laying the foundations for the framework (Marques et al. 2004).

Ideation is the creative process of generating, designing, and communicating new ideas, comprising all stages of a thought cycle and the fuzzy front-end phase. Gero and Kannengiesser (2004) proposed the function-behavior-structure (FBS) framework. The FBS situates the act of designing at the interfaces between an expected world, an interpreted world and an external world, linked by six fundamental design processes: formulation, synthesis, analysis, evaluation, documentation, and reformulation. Howard et al. (2008) presented a framework for the creative design process based on the integration of the engineering design and cognitive psychology fields. To close the gap between engineering design and cognitive psychology Howard et al. (2008) proposed an improved version of Gero's FBS framework. Three additional creative components were then mapped onto this framework: analyses of creative tasks, generation of ideas, and evaluation. The C-K design theory was presented by Hatchuel and Weil (2003) and is based around the interplay between two independent spaces: a concept-space and a knowledge-space. The interplay is mainly accomplished by moving from the concept-space to the knowledge-space. In the C-K theory, the concept-space holds ideas that are neither true nor false, meaning that they are exploratory concepts that will immediately pass onto the knowledge-space which holds a kind of tacit knowledge. Chusilp and Jin (2006) proposed a cognitive activity framework of conceptual design based on four cognitive activities: analyzing, generating, composing, and evaluating the problem.

Three important iteration loops were identified: problem redefinition, idea stimulation and concept reuse - creative design engages in more iterations than routine design. Hsiao and Chou (2004) developed a creativity method based on the sensuous skills of humans called the "sensuous association method" (SAM), allowing the production of creative ideas in a surrounding environment. The SAM consists of four intrinsic personal human behaviours derived from the senses: looking or information input, thinking or inference and re-association, comparing or extraction and restructuring, and describing or creativity output, and one extrinsic behaviour.

The framework to be presented intends to deal with three aspects of design: linear versus iterative processes, heuristic versus algorithmic search for new concepts, and the application of tools for decision-making with limited information. The first concern is directed at linear versus iterative processes - simple design processes shown a linear perspective while others can accommodate iteration - from the fact that design is evolutionary and needs to constantly loop backwards for redesigning and testing. Heuristics are not based on traditional mathematical grounds as algorithmic procedures are. The major concern of using algorithmic procedures in creative design is that the former typically converge to a single solution while the latter has no unique outcome. The third concern encompasses the inherent difficulty in evaluating half-baked ideas that emerge whenever an artefact is being designed. Again, the problem is generally solved in formal frameworks with the help of some algorithmic method when most of the time the right decision can be made with a simpler heuristic approach. Before moving on to the explanation of the proposed Ideation Framework (IF), it must be noted that the outcome of the framework is not a new product or service, but merely a new concept for a product or service (Marques et al. 20144). After the presentation of the framework, the authors diverge to a literature review that considers further considerations of the framework to innovation's outputs - regarding technology and business models- and a possible relationship to architecture's (product-service) issues.

The ideation framework (IF) was developed by the authors and its conceptual background is to be presented elsewhere (Marques et al. 2014). The IF is visually represented in Fig. 1. The framework encompasses three important domains: 1) inspiration, 2) decomposition and 3) integration. A dashed line between the decomposition and integration domains means that there is no clear separation between the two. Within each domain, there are mechanisms, heuristics, methods (e.g. Rosenman and Gero 1993, Welling 2007, Linsey et al. 2008, Frey et al. 2009) that act upon the flow of ideas to come up with a creative concept. These domains will be briefly explained in the following paragraphs sections.

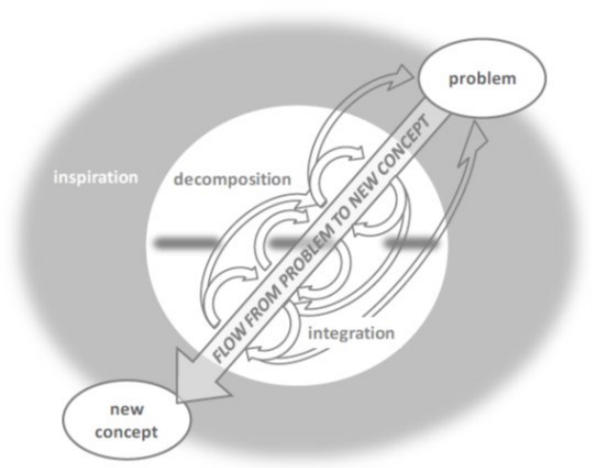

Fig. 1 General view of the IF (Marques et al. 2014).

The *inspiration* is a necessary source for designing new products and services. Inspiration is driven mainly by scientific discoveries, technology achievements and opportunities from business and market surroundings. In fact, different design teams will have different inspiration domains, depending on their educational and personal background and their lifelong experience. Within the inspiration domain lays not only the "problem-space" but also the "idea-space". The former encompasses the problem to be solved and all the information relating to it, while the latter accommodates all the possible ideas brought in to solve this problem. One can say that the idea-space needs at least to intersect the problem-space or no valid idea can be found to solve the problem at hand. We will call this intersection of problem-space and idea-space the "concept-space" Fig. 2 shows a schematic of the spaces superimposed on the IF.

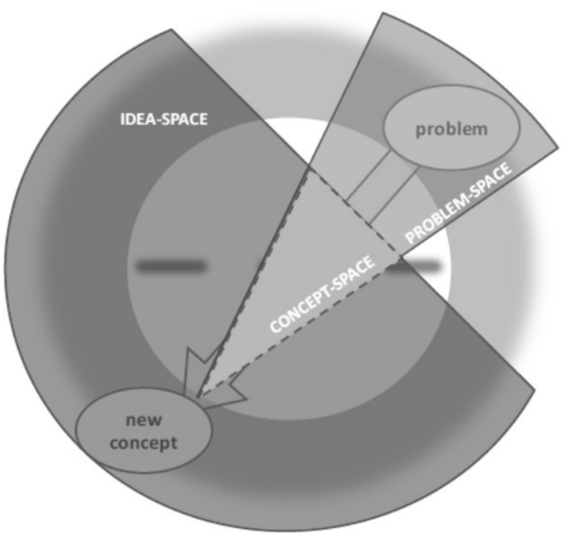

Fig. 2 The problem-, idea- and concept-spaces superimposed on the IF (Marques et al. 2014).

Within *decomposition*, a company essentially breaks the problems, ideas and concepts into smaller subsets - the decomposition can be an abstraction of the problem to be solved, ideally setting measurable goals for the design to be developed. In a typical engineering design process, this approach to decomposition would be like understanding and identifying customer has needs and consequently setting specifications as goals for achieving customer satisfaction. Decomposition can also be accomplished as idealized functional requirements that the product and/or service are expected to fulfil. An essential element of the IF process is that these abstract specifications or idealized functions will be taken up by the "integration" domain in the form of abstract information (Fig. 3). Much of the decomposition may take place in the problem-space, as a company may not be thinking at this point of a solution to the problem. If, however, a company is already at this stage imagining a solution to the problem and is using this to construct the idealized functions or target specifications, then we must place this activity between the problem-space and the idea-space. The integration domain uses all the information derived in decomposition to explore the idea-space in search of a solution to the problem (Fig. 4). The tentative ideas that are formed in this process constitute the concept-space. The concept-space is the part of the idea space that has relevant information to the problem at hand, so it is one of the possible intersections between idea-space and problem-space – in fact, every tentative idea is an intersection of problem-space and idea-space.

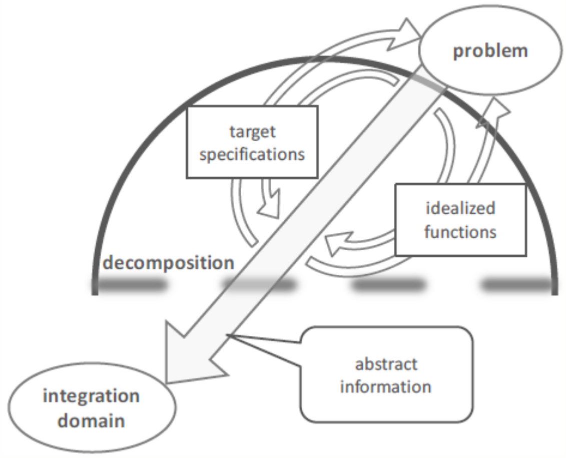

Fig. 3 Decomposition of the IF (Marques et al. 2014).

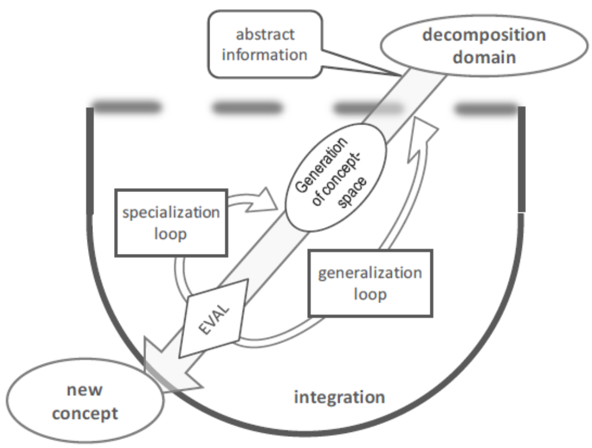

Fig. 4 Integration of the IF (Marques et al. 2014).

The evaluation is done by comparing the functions or the performance of the concept against the functions or the specifications derived earlier in the decomposition domain. This test can lead to three outcomes: first, the tentative concept shows all the functions and meets all the specifications, therefore becoming a possibly acceptable new concept; second, the tentative concept shows only partial fulfilment of both functions and specifications, but a company believes that the concept can improve with some refinement, therefore going backwards on a specialization loop within the same concept-space; and third, either the concept is completely off target or successive specialization loops have failed to bring it to fruition, and something more radical needs to happen – a company must form another concept-space and start all over again, this is called the generalization loop. There is evidence of specialization, generalization and mid-term loops in the human mind (Ware, 2008) thus pointing out the inherent iterative nature of PSS design activities. This iterative nature of the design activity includes feedback loops: the specialization loop – typical of concepts that are incrementally derived from existing products and/or services within the same concept-space – and the generalization loop – typical of concepts that may constitute breakthrough innovations in different concept-spaces. A middle term loop is also most probable to exist to characterize what Davila et al. (2006) calls of "semi-radical innovation". The three types of innovation's outputs (proposed by Davila et al.) and used in this paper are summarized in Table 1.

Table 1 Innovation matrix (adapted from Davila et al. 2006).

Innovation Matrix

Technology \ Business Model	*Near to the existing*	*New*
New	Semi-radical	Radical
Near to the existing	Incremental	Semi-radical

Special attention to the gates (evaluation item in Fig. 4) in the IF that guide the specialization and generalization loop is necessary for possible implications of the IF on product/service architecture. There is a need to identify a possible saturation in the specialization loop, denoting that there are no other improvements at technological and/or business model levels, without changing the concept-space, or changing the architecture. In terms of a product/service's language, one is talking about improvements and optimizations preserving an architecture, which is, achieving a better product-service within the same concept-space. Theoretically, when the potential for improvement is saturated, innovation on the product-service needs breakthrough, which means novel approaches, requiring a paradigm shift and/or the replacement of items in the concept-space. More precisely, the generalization loop could be a change of a concept-space, but is also a change between different architectures. New product-services tend to have an integral architecture, however with the increasingly short life cycle, their architecture becomes modular over time, reducing cost and increasing product-service variants (Baldwin and Clark, 2000). This leads to the hypotheses that the framework should work in dissimilar ways for new products-services and for incremental ones, thus interfering with architecture decisions. Theoretically, product-service systems' architecture should be interconnected with creativity.

3. Methodology

This paper follows a case study research methodology (Yin 2009). Thus, we have defined the following assumptions and constrains for this case:

- Since the case study is interpretive, we rely on ours' observations and interpretations.
- Our main role, as researchers, was to access other individual's interpretations, thus filtering those opinions over a proposed conceptual framework.
- Not only individuals' responses will be limited and rationalized, but there is also interference from the researcher's subjective interpretations and questions.
- One should acknowledge that bias is present in both actors, particularly in a unique case study.
- During data gathering, the authors decided to be only external observers.
- The unit of analyses focused on the case of Via Verde system's innovation during the period between 1990 and 2010.
- The data collected was qualitative and considered more appropriate.
- Interviews were the primary data source.
- Other sources, such as web, project reports and two books (Brisa 2006, 2010) were used to triangulate information from the interviewed phase.

Regarding interviews: They were semi-structured and questions were defined according to each role of the interviewed person on the company. The following questions were asked:

1. "Via Verde" was born in 1991. What was the specific purpose for it? Could you please focus your answer on business and technology issues?
2. The name/brand "Via Verde" had an objective?
3. The idea of moving from an "opened toll system" to a "closed system" occurs with the massification of Via Verde in 1995?
4. In 2000, the idea of an "access service" occurs, however it fails. Was there a reason for that?

5. Within a paradigm of innovation, many projects were created, such as "ITS-IBus". Can you characterize them regarding technology and business models?
6. Is the company no longer dependent on software with the "ITS-IBus" concept? What kind of business model supports this technology?
7. Are open software/systems normally associated with "open innovation"? How do you characterize the architecture of Via Verde?
8. What are the plans for the company?

The interviews were transcribed to paper recurring to the notes that were taken during it. The number of interviewed persons was a total of six:

- From Brisa Innovation: The Director, the person Responsible for the Technological Development Process, one former Expert Engineer involved in the design of Via Verde system, and an Engineer involved in the innovation process.
- From ISEL (Polytechnic Institute of Lisbon), the Project's Coordinator between ISEL and Brisa.
- The Manager of an outsourcing company collaborating in different projects.

4. Results

This section describes in detail the innovation process of "Via Verde". We first provide a short case summary. This is followed by a closer analysis of the type of innovation's output, based on the answers from the interviews and consulting other sources of information (web and reports/books), as well as a section highlighting key issues related to the framework.

Overview of the case company

Brisa was founded in 1972. In nearly four decades become one of the largest operators of toll motorways in the world and the largest transport infrastructure in Portugal. Today, Brisa has a market capitalization of around 3000 million Euros and its shares are listed on Euronext Lisbon, where it integrates its main index, the PSI-20. The company is also a part of the Euronext 100 - an index that includes the largest companies in France, Holland, Belgium and Portugal - and the FTSE4Good, the reference index in social responsibility. The main business area is the construction and operation of toll motorways and the remaining businesses consists of the provision of services associated with the safety or convenience of traffic road on the motorway and urban environments. In the international market, the company operates in the USA, Holland, Brazil, India and Turkey. Brisa Innovation is integrated in Brisa's Group that is strongly committed towards the promotion of mobility as a driver to create important economic and social benefits for the communities that it serves. Brisa Innovation mission is to research, develop, integrate, install and maintain technological solutions for ITS (Intelligent Transportation Systems), acting as competence state-of-the-art center, with a view to ensure maximum quality and efficiency in deployed solutions.

The first steps: incremental innovation as we see it

The company was pioneer in the development and implementation of a new automatic toll system called "Via Verde". Installed in 1991, in four toll plazas, by 1995 the system had extended to the national motorway network, with over a million users:

The extension of the national roadway system and the resulting vehicle flow raise granted us to search for the best practice for a new toll automatic collection solution…The goal was to work out on a toll collection model allowing the client to go throughout the toll gate, devoid of stopping the vehicle and using an access lane, correctly identified and equipped. (Former Expert Engineer)

For that purpose, before 1991, a company's teamwork composed by technical experts and commercial staff travelled to Norway (Brisa 2006) to visit "Q-Free" company, which had developed a simple system to control the access ways to a small city. The observation of the operating technology already developed, turned out to be the necessary inspiration to build an in house new system. Absent to the system in use, there was the need to identify the vehicles per class (four classes are used according to national legislation, book) by measuring physical parameters; a mission that would be possible by setting up sensors on the paved highways. An innovative challenge was the development of an algorithm for "Automatic Vehicle Classification" (AVC). The next step would engage the association of the vehicle's classification and identification by means of a device placed on its windshield. In 1991, the company's technical staff started developing equipment adapted for the national context. All the work performed allowed the company to classify the traffic that has passed through the tolls, as well as collecting the toll payments using a bank debit card – a system that was made feasible thanks to "SIBS" clearing company's know-how. The missing point was the name that would match all this technologies and business models to release Via Verde in 1991. The inspiration came once again from outside – an analogy to the postal service "Blue Post":

Company's innovative system was green, representing lower levels of pollution, and the green *light represents that you can go in a traffic signal. (Technological Development Process Responsible)*

The next step consisted in the application of Via Verde to the "closed-system" applied over a bigger highway network (Brisa 2006). Subsequently, in 1995, Via Verde's second stage had taken place, and the company provided the necessary equipment to all the operating toll plazas (around 60). In 2000, Via Verde's autonomy from Brisa occurred as the company was under privatization. Two years later, the "access service", which consisted in a pack of benefits annually paid, including parking and petrol station payments as well as many insurance covers were released and not successfully achieved its objectives:

The public´s weak acceptance to this service, the lack of experience in the insurance universe, and the clear delay in technology led to its abandon…reconsidering new objectives in the market based on a new business model of the company, and most important the company's internal organization change (Former Expert Engineer)

<u>The second stage: radical innovation?</u>

In 2002, the creation of a "Direction of Innovation and Technology" (DIT) clearly showed the acknowledgment of the importance to promote and develop innovation policies. A pilot project (a+) was taken into practice with the objective of creating good conditions to the generation of new ideas and build an innovation culture (Brisa 2010):

The project (a+) is the concretization of Brisa's innovation model. The innovation was developed jointly with start-ups…mainly driven by the necessity of strengthen the research, development, and innovative solutions for toll equipment plazas, access control to parks, and payment systems in services stations (ISEL Coordinator)

Based on collaboration between Brisa and ISEL, a new project contributed considerably to the innovation of "Via Verde". The project is the recognition of three crucial points: the launch of an infrastructure with open protocols and interfaces (standards); a new incorporated payment system; and the enlargement of Via Verde's business model to other areas. The project aimed the development of an infrastructure with open interfaces and protocols that can integrate internal and external business processes, relating dissimilar companies or organizations:

The solution is based on ITS-IBus (Intelligent Transport Systems Interoperability/Integrative Bus) project concept…this idea supports the normalization of services and interfaces based on interoperability, representing the shift from a monolithic approach to automation islands in infrastructures, from closed systems to open ones. (Outsourcing Manager)

As a result, clients will organize their services according to their exact needs, while the company organizes it in terms of business processes, technical resources, and flexibility in using equipment from different contractors. The project also catalyzed other forecasts such as automatic systems for toll collection beyond Via Verde's system, and the redesign of toll cabins in terms of modularity and ergonomics (Brisa 2010). In summary, "Via Verde" PSS started in a "closed innovation context". That was visible in the intention of building an in-house system, reinforced with the difficulties in acquiring sufficient mass technology from suppliers in its second stage. With the creation of the DIT, the situation has radically changed. The ISEL collaboration in the ITS-IBus project "is an excellent case of openness":

The constitution of an innovation network that allows the transference of knowledge reflects a new paradigm…Spin-offs were created and different partnerships achieved…With open innovation, open source or free software taxonomy is also present. (Director)

5. Discussion

Based on the case presented, we can now propose a matching between it and ours' ideation framework. Keywords from the previous section allow us to start identifying, at least, the inspiration domains, and the problem-, idea-, and concept-spaces of the PSS. Via Verde is a typical case of applied creativity that can be explained by the proposed ideation framework. The "inspiration" domain is visible in the initial solution required to avoid long-time waiting lines in the national highways (opportunities from business and market surroundings) and the existent Norwegian's Q-Free system (technology achievements and further improvements). Within this inspiration domain, lays not only the problem-space but also the idea-space as we have mentioned before (see literature review). The problem-space, in the first stage, is characterized by the need of developing and implementing a new automatic toll system. The idea-space is characterized by a solution that allows people to go throughout a tollgate, devoid of stopping the vehicle and using an access lane, correctly identified and equipped. Within this intersection of problem- and idea-spaces lies the concept-space(s). In the first stage, it be the need to identify classes of vehicles, the development of an algorithm for AVC, and the association of the vehicle's classification and identification. This is in terms of design of PSS quite like the understanding of needs/requirements translated into setting up product/service's specifications. In terms of the integration domain, we can draw the following considerations: Before 2002, one can characterize Via Verde's PSS as being not much more than a group of incremental solutions. The idea behind "Via Verde" was based on a technological incremental innovation and on similar business models. In 2002, the DIT was created and has coincided with the failure of the "access service". It is also by that time that we can sustain the thesis that "Via Verde" started to shift from an "incremental" innovating context into a more "radical" innovation new paradigm (between these two stages semi radical innovations occurred, but with difficulties in identifying precise periods or situations). Considering an analogy to ours' framework, one might precise that the initial "specialization loop" of the integration domain was becoming saturated at both technological (e.g. lake of interoperability, great dependence on suppliers of technology) and business model (e.g. extended services, lake of partnerships and networking communities) levels. Thus, in 2003, "Via Verde" started the implementation of the ITS-IBus project. The PSS entered a new cycle due to costs reduction and the independence from their suppliers of technology. This situation allows new developments in emerging technologies supported by new business models. For example, the technology/concept/process behind the ITS-IBus enabled other expertise in a favorable "opened" world context. Indeed, nowadays, Brisa manages and owns the technology behind Via Verde and all associated services to the system with a new value propositions. Which regards the possible connection between creativity and system's architecture we can enunciate the following hypothesis: The new extended Via Verde concept, prior to a lock-in system, is now agreeing open protocols and standards, disintegration and interoperability, contributed this way to a shift of the PSS's architecture:

Brisa is nowadays seen as an integrator of systems based on a plug-and-play architecture. (Innovation Engineer)

The former sentence is what we can call a fundamental characteristic of modular architecture (Ulman 1997, Yu et al. 1999, Baldwin and Clark 2001). In other words, Brisa's Via Verde system has overcome from an initial integrative architecture to a modular one, as displayed in Fig. 5.

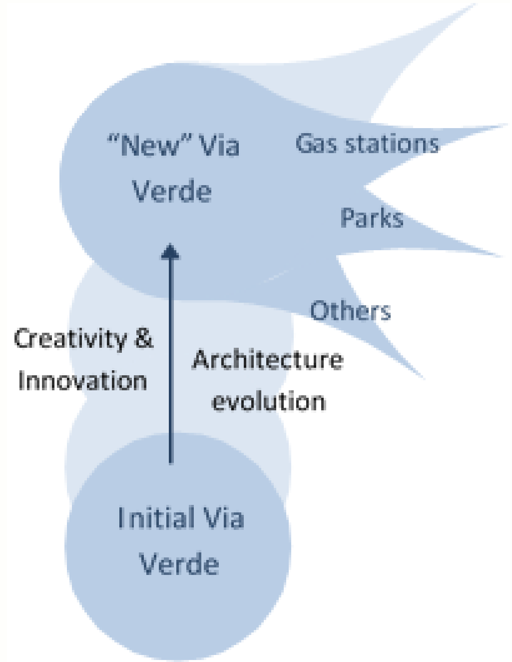

Fig. 5 Via Verde system's architecture evolution over the period of 1990-2010.

Lastly, one should notice that the IF was first developed for academic proposes and this is the first attempt to use it in a real case study - our future goal is to turn it on a prescriptive framework of creativity and innovation for successful companies. Based on that, managerial implications are expected if regarded as guide for good practices.

6. Conclusions

The main objective of this paper was to make a correspondence between a proposed framework of the ideation process and a case study in the industry that we believe to help explaining how creativity contributes to the different types of innovations in companies. To address that objective, we have evaluated the innovation of a specific PSS and compared it with the framework, answering this way to the two research questions. First, the ideation model appears to be consistent with the empirical findings concerning the spaces and the domains of the framework. Additionally, and as observed, the specialization loop is typically used to generate incremental outcomes, while the generalization loop typically represents breakthrough innovation. Secondly, and in the case of a blocking situation in terms of technological and/or business model's innovation, we believe that the framework shifts its approach from a specialization loop into the generalization one. By other words, this is equivalent to say that for this PSS a change from an initial integrative architecture to a modular one has existed, which then allows innovation to occur. There have been studies in recent years on product/service architecture and its implications in design (Stone et al. 2000, Dahmus et al. 2001, and Yassine et al. 2003, Tyson 2009) and the recognition of a hypothetical connection between the constant change of the design and the changes enforced in the final product/service architecture. The study conducted so far presents limitations to the above findings. They rely on in-depth case study of one industrial company operating in the highways industry. Thus, the findings should be considered as applying first to contexts characterized by similar conditions. For instance, a PSS transition that lacks an installed base logic would probably look different. Furthermore, given that the findings are based on one case, replication across more cases enhances their generalization. Finally, the use of "near-to-existing" and "new" without any real attempt to make this measurable is also a matter of great discussion. There is a smooth distribution of change ratios and not only three types as invocated in the paper. The change ratios are dependent more on the technological/business model area than they are on the level of novelty or on any ill-defined innovation type. To go over this problem, we propose the future use of modulation's trend of the framework, allowing inputs and outputs to be probabilistic and continuous.

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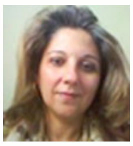

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Improving Power Scooter in Systematic Innovative Thinking

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Abstract

With the improvement of medicine and health care, the elderly are facing the dilemma of independent mobility Because the life expectancy of people in Taiwan has greatly increased. And the population structure of this society has been ageing rapidly. At this time, the power scooter is the most important action aids in life, so the design of safety of power scooters is a vital factor, especially in the initial launch, out of control scooters likely to sudden unintended acceleration (SUA). In order to prevent all possible accidents, it is essential to ensure that the scooter is in a safe state when traveling along a route. In order to deal with these problems above, our study proposes a Triz-based theory by redesigning the speed controller system. Firstly, use the method of The Systematic Innovative Thinking defines the potential problems and key disadvantage. Then, take use of Contradiction matrix and 40 Inventive principles to target solution. Finally, by using Trimming tool to delete unnecessary elements. These methods can maintain functional integrity of power scooters and increase the safety of people who take the vehicle. The study improve speed controller system of power scooters and add PWM and Soft-starter to correct the problem of sudden unintended acceleration. Power scooters traffic accidents caused by improper handing have declined greatly. Provide the elderly a kind of safe assistive devices for independent mobility.

Keywords: Elderly, Power scooter, Sudden unintended acceleration (SUA), TRIZ

1. Introduction

The world population is ageing at a rapid pace. In 2006, nearly 5 billion people worldwide were 65 years and older. But ten percent of the worldwide population has disabilities, and it is estimated that 65 million people need manual or powered mobility devices.

Maintaining independent mobility is an important goal of clinical medicine and public health, especially in older persons, who are at the greatest risk for functional decline and disability.

Mobility outside the home is essential for social inclusion and is associated with various positive health indicators.

Assistive devices-such as wheelchairs, power scooters, canes, crutches, and walkers—are effective ways to alleviate the impact of mobility limitations for many people, allowing improved ambulation and independence.

A scooter is a power, usually battery electric, vehicle, typically for a person who is able to walk but is not able to walk long distances. For psychological reasons, scooters are designed to look more like a Motor-scooter than a wheelchair.

The elderly will face the difficulties of moving independently because of physical degenerating. Power scooters will be the most important moving assistant. And under this situation, the safety of power scooters is a vital factor, especially when starting, it will cause damage to the elderly due to its SUA.

When the elderly are riding power scooters, if they don't set the Speed-control to the most suitable or the lower speed in advance, it may lead to damage to people or scooter when setting in motion.

Fig. 1 is the comparison of Total Fertility Rate and Elderly Rate. Among these countries, the rate of the elderly people in Japan is 24%, it has gone into hyper-aged society. Other European countries are between "aged society" and "hyper-aged society". As for Taiwan, rate of the elderly is 11% (which below 14%, the definition of aged society). However, the fertility rate in

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Taiwan is quite low, it will speed up the process of aged-society.

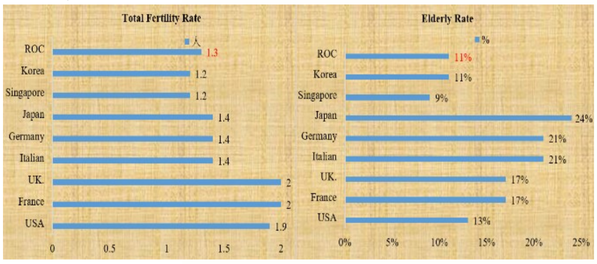

Fig. 1 The Comparison of Total Fertility Rate and Elderly Rate

With the growth of age, our body organs will react slowly, function will degenerate gradually, and come with chronic disease. The elderly can deal with some leisure activities when facing them, while the environment has changed or been complicated, it's hard to settle the situation for the elderly because of their physical decline and will affect the ability of taking use of space. Hence, it is important to construct a convenient and safe public transportation for the elderly, to make sure they can move freely without help, and avoid accident happens in our daily life.

In order to adapt the inconvenience caused by aging, human beings invented some assistant to help their daily lives. The assist is vital for the elderly and the disabled, it can help those who suffer from moving difficulties to regain the ability of walking and take basic activities in their daily lives.

With the development of technology, complementary assist has changed from wheelchair to electric wheelchair and today we can see power scooters everywhere. These assist complement should be innovative and novelty, and consider the need of the elderly and the disabled.

Some good creativities are workable in theory, but in reality, it's hard to realize because of some design deficient. This kind of patent is what we called- half invention. Therefore, the work of invention had better be out of the purpose of "need" because it will be accepted easily by market. （Huang, B. Z. and YE, Z. F. 2005）

Among various kinds of solutions, traditional Brain Storming tend to make no progress; Design of Experiment tend to consume resource. As to TRIZ, it emphasize the invention or innovation can find out answers to the problems by system methods.

Amar Bhide, professor of Harvard University, once did a study and show that 71% of successful innovation are from cloning or revising some former experience or knowledge.

2. Research Method

Elderly aids are often regarded as the most crucial aspects of new product development in health care. Innovative methods in power scooter design most commonly used the Theory of Inventive Problem Solving (TRIZ).

The Soviet inventive problem solving method, TRIZ, is built on over 1500 person years of research and the systematic study of over 2 million of the world's most successful patents

(1) The first step is to take 6W1H1G, 9/12 Windows Analysis, Ideal Final Result to describe questions, and discuss about Problem exploration, Opportunity identification.

Use 7 questions to help researcher understand the details and aspects for each question. Take 6W1H1G to describe questions, and discuss about Problem exploration, Opportunity identification. These can help limit the range of research. (Hou , Chun Ting, 2011)

9/12 Windows Analysis Help research observe the nature of questions through different space /time. To delimit time to past, present and future with different axis to time and analysis questions. Then it can be divided into sub-system, system and super-system. We can understand the trend of evolution of the system. (Mann, D.L.,2001)

Traditional solutions to engineering problems take persistent improvement with the same way. However, its efficiency will decline gradually. The ideal final solution is the best answer to a question. An ideal system means: ideal machine, ideal method, ideal process, ideal solution, ideal resource (Savranksky , 2000)

(2) The second step is to take Patent Analysis, Function Analysis, Root contradiction analysis Conflict identification and analysis tool to find out the harmful function of a system.

Among all technique documents, Patent document has the strongest legal force and application of industry. Take good use of patent retrieval method can help us understand our competitors' next step and can control overall development of industry technique accurately. (Chen, S. S., 2011)

Function analysis is a method to divide a system into component and sub-system, analysis how each component and sub-system work, realize the surface problem and help user recognize function and damage to each component.

RCA (Root contradiction analysis) this method is to find out the harmful function of a system, the cause-effect and conflict. When these root-related problems are solved, surface problems are solved as well.

(3) The third step is to take Contradiction matrix and 40 Inventive principles for innovative research and development, then taking Trimming tool by the way of removing components, cut costs, reduce system complexities, improve system reliability.

TRIZ is a method invented by Genrich Alshuller, a professor of Soviet Union, by analyzing hundreds of thousands of parent documents and issued solutions to problems.

The commonest tool is contradiction matrix made up by 39 Improving Parameter and 40 Inventive Principle. We can get a proposal to improve our product from the connection of the two parameter. One is from 39 Improving Parameter, the technology and physical contradiction appeared during the process of development. The other is 40 Inventive Principle which was concluded from patent analysis.

Trimming means that using the way of reducing component to improve the system and increase its perfection. User must consider the figure of each component under different aspects, collect these results, and arrange the order that will be deleted till we can't delete any component.

This paper explain the procedure of TRIZ. Take Speed-Controller as an example, to tell the way to solve the SUA. problem when starting the power scooter. TRIZ solution and the complete problem solving flow as Fig. 2.

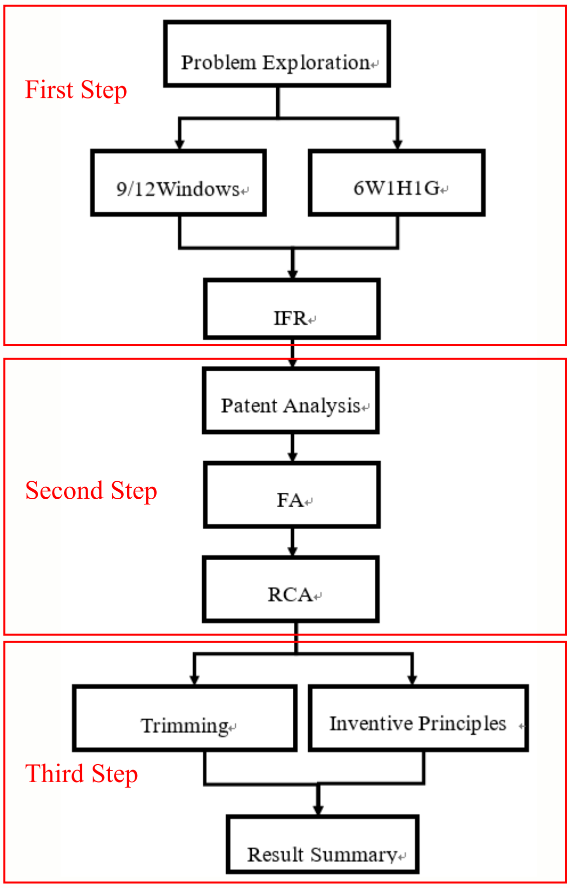

Fig. 2 Procedure of Research Method

3. Questions Description and Solution Procedure

The commonest incapability problem for the elderly is degeneration of moving independently. Power scooters can provide the elderly with convenient means to maintain their basic ability in their daily lives.

According to investigation, the power scooters sold today, as Fig. 3, use manual rotary switch to control the moving pace of Power scooter.

	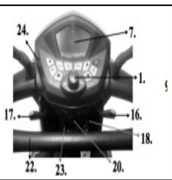	
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Fig. 3 Models of Power Scooter sold on market

When the elderly are riding power scooters, if they don't set the Speed-control to the most suitable or the lower speed in advance, it may lead to damage to people or scooter when setting in motion.

(1)6W1H1G

Use 6W1H1G to describe the problems caused when the elderly are riding power scooters, then discuss the problem of power scooters and recognize the opportunity(Op), Table 1 6W1H1G Problems Description.

Table 1 6W1H1G Problems Description

6W1H1G	Answer
What Problem?	Power Scooter sold on market SUA. easily
When was it happen?	Power Scooter SUA. when starting
Why did it happen? Or why did we discuss?	The need of riding Power Scooters
Who will be affected?	Power scooter SUA. will cause car accident and lead to the injury of riders
How was it happen?	Without setting the Speed-control to the most suitable or the lower speed in advance, it cause to SUA.
What to do?	Power scooters can move slowly when starting

(2) 9/12 Windows Analysis

In 9/12 Windows Analysis, the analysis between normal use and abnormal use with Life cycle as Table 2 and Table 3.

Table 2 9 /12 Window Analysis (normal use)

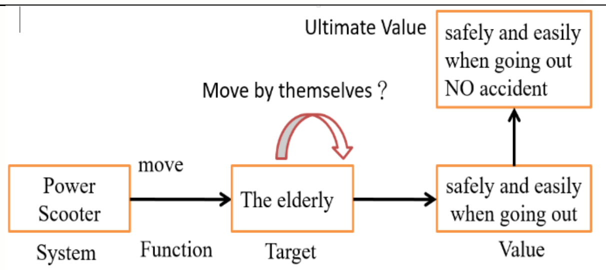
	Past	Present	Future
Super-System	Power scooters are displayed and for sale in Medical equipment Store	User, roads, traffic sign and disabled access	N/A
System	To assemble and pack in the factory	Power scooters	Out of electricity and need to be charged and maintained.
Sub-System	To produce and assemble machine parts	ECU, Motor, wheel, dashboard, handle and brake	To maintain and revise machine parts

Table 3 9/12 Window Analysis (abnormal use)

	Past	Present	Future
Super-System	Power scooter are displayed and for sale in Medical equipment Store	User, roads, traffic sign and disabled access	Power scooters breakdown and are destroyed.
System	To assemble and pack in the factory	Power scooters	Power scooters SUA. and bump when starting.
Sub-System	To produce and assemble machine parts	ECU, Motor, wheel, dashboard, handle and break	The function and appearance of machine parts can't be repaired.

(3) Ideal Final Result, IFR

IFR means power scooters won't SUA. when starting just because the user doesn't set the speed-control in advance. The elderly and the disabled can ride them safely and easily when going out, as show Fig. 4



System：Power Scooter

Function：move

Target：The elderly

Value：safely and easily when going out and no accident

Problem：no soft starter

Fig. 4 Power Scooters Ideal Final Result Table

(4) Patent Retrieval , Analysis

Power scooter sold on market provide those who are unable to move freely as transportation. According to some patent, we could understand that its speed is controlled by speed-control. The speed-control consists of Potentiometer, as new patent M266892(Lin, X. Q. and Ding, Q. H. 2004), an equipment of constant speed which includes speed setter, speed-controller and speed setter items, the patent procedure as Fig. 5. Power scooters can control the pace of moving by speed-controller and make Motor set speed by speed setter, then power scooter can move with the same speed.

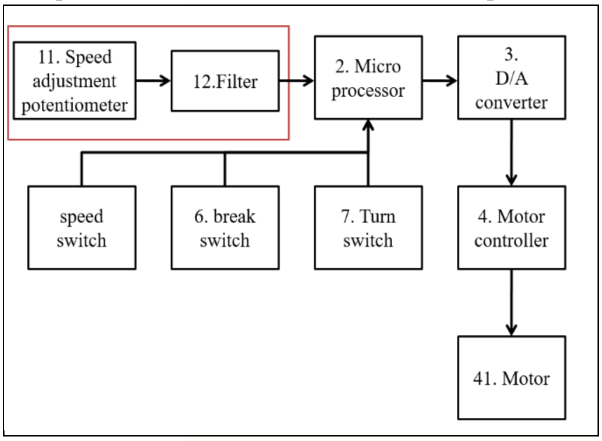


Fig. 5 M266892 the patent procedure

By new Patent M266892, we can get the independent claim and the dependent claim of this patent, as Fig. 6; next, analysis the operation between patent range and component in independent claim, get the independent Claim Genealogy, as Fig. 7. If we can avoid the content of independent claim, we can prevent from infringement. (Sheu, D. D. 2016)

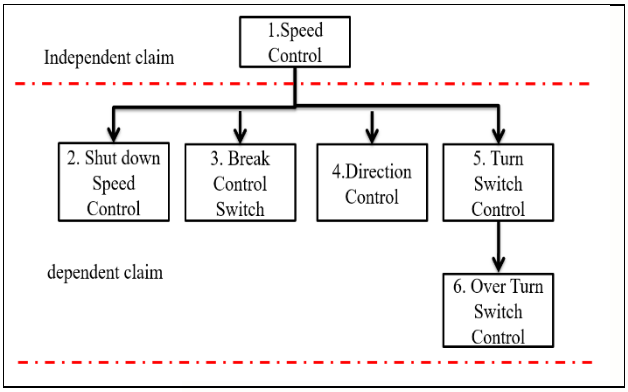


Fig. 6 Independent claim and attachment

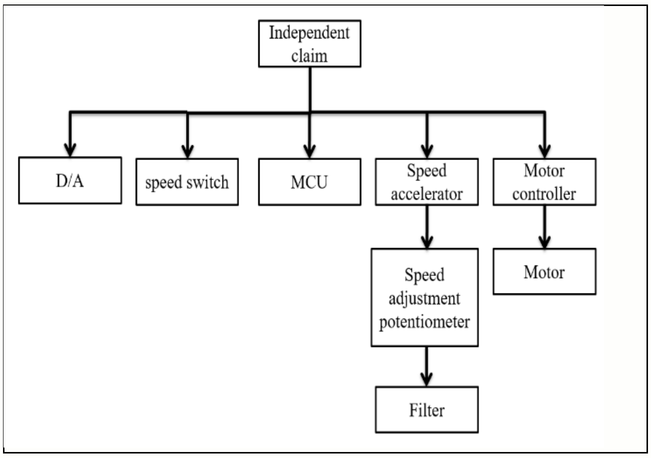


Fig. 7 Independent Claim Genealogy

(5)Function Analysis

To divide the power scooter into two types, one is engineer system and super-system component, as Table 4.

Function Analysis (Component Model)

Engineer System：Soft starter

Main Function：Make sure it won't sudden unintended acceleration when starting.

Table 4 Component Model

System Component	Super System Component
Speed accelerator	The elderly
Speed adjustment potentiometer	
Filter	
D/A converter	
Motor control	
Motor	
Turn switch	
Break switch	
Speed switch	

To define function attribute of each component, as Table 5

Table 5 Function Modeling

Function	**Object**	**Category**	**Rank**	**Performance Level**
The elderly				
Rotate	Speed accelerator	Harmful	B	E
Speed adjustment potentiometer				
Supply voltage	Filter	Harmful	B	N
Filter				
Supply voltage	Microprocessor	Harmful	B	N
Microprocessor				
Transmit digital signal	D/A converter	Harmful	B	N
Speed switch				
Transmit signal	Microprocessor	Useful	B	N
D/A Converter				
Transmit signal	Motor controller	Harmful	B	N
Motor controller				
Supply voltage	Motor	Harmful	B	N
Motor				
Rotate	Power scooter	Harmful	B	N
Power scooter				
Move	The elderly	Harmful	B	N

U-Useful function — H-Harmful function
Performance (U) — I-Insufficient level — E-Excess level — N-Normal level
Rank B-Basic — Ax-Auxiliary — Ad-Additional

After realizing function Supply by each component, we can understand the interaction of each component and the function of each component by Table 6.

Table 6 Interaction Matrix

From/to	**Speed accelerator**	**Speed adjustment potentiometer**	**Filter**	**Micro processor**	**D/A Convert**	**Motor controller**	**Controller**	**Turn switch**	**Break switch**	**Speed switch**	**The elderly**
Speed accelerator		+	+	-	-	-	-	-	-	-	-
Speed adjustment potentiometer	+		+	-	-	-	-	-	-	-	+
Filter	+	+		+	-	-	-	-	-	-	-
Microprocessor	-	-	+		+	-	-	+	+	+	-
D/A convert	-	-	-	+		-	-	-	-	-	-
Motor control	-	-	-	-	+		+	-	-	-	-
Motor	-	-	-	-	-	+		+	-	-	-
Turn switch	-	-	-	+	-	-	+		-	-	+
Break switch	-	-	-	+	-	-	-	+		+	+
Speed switch	-	-	-	+	-	-	-	-	-		+
The elderly	-	+	-	-	-	-	-	+	+	+	

By drawing Function Analysis (FA), we can tell the differences between normal use and abnormal use, as Fig. 8 and 9.The symbol table by Table 7.

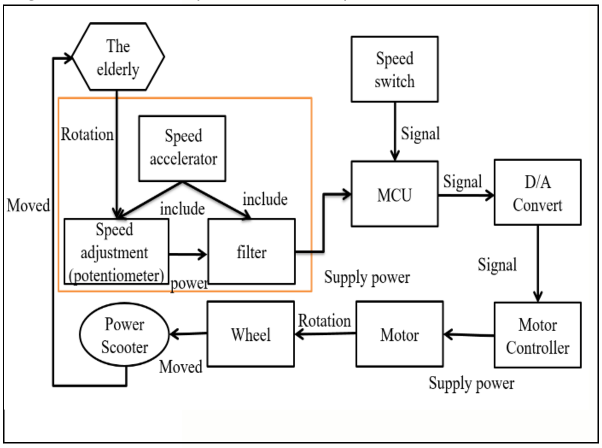


Fig. 8 FA (normal use)

Table 7 Symbol Table

Symbol	Mean
⟶	Useful
– · →	Harmful
==⇒	Excess

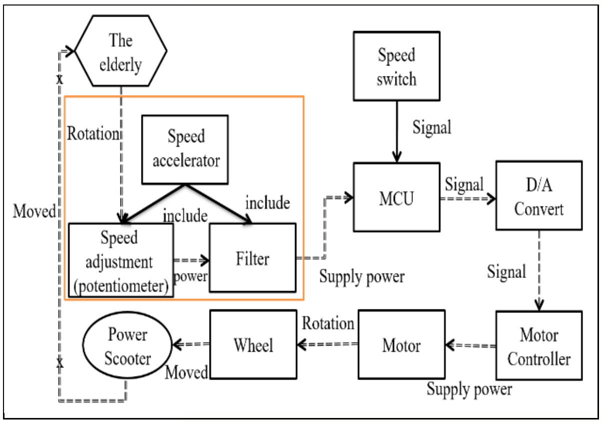


Fig. 9 FA (abnormal use)

(6) RCA (Root contradiction analysis)

The research is to find out the key negative factor of power scooters, the procedure as following, and the result as Table 8.

What's problem? There are some deficiencies in power scooters because of wrong operation and lead to SUA.. This study hopes to improve system parameter 31 "Objects produce harmful factor"

Why? Because the Motor control transmit the wrong voltage level when Motor starts. This study hopes to improve system parameter 27 "Reliability" and system parameter 9 "Speed".

Why? D/A converter transmit the wrong digital signal because of microprocessor. This study hopes to improve system parameter 27 "Reliability"

Why? Microprocessor transmits the wrong voltage level because of Filter. This study hopes to improve system parameter 27 "Reliability"

Why? Filter transmits the wrong voltage level because of speed adjustment potentiometer. This study hopes to improve system parameter 27 "Reliability"

Why? Speed adjustment potentiometer is rotated excessively. This study hopes to improve system parameter 33 "Difficulties of operation", system parameter 32 "Difficulties of produce" and system parameter 36 "Complication of equipment"

Contraction: According to the Root contradiction analysis, summarize the corn problem, system parameter should be improved is system parameter 9 "Speed", parameter 27 "Reliability", parameter 31 "Objects

Produce harmful factor" and parameter 33 "Difficulties of operation". As for parameter 32 "Difficulties of produce" and parameter 36 "Complication of equipment", we can use Contradiction Matrix to find out some principle to correspond to.

Table 8 Root contradiction analysis

Why	Answer	Parameter Involved	worsen
What is Problem?	There are some deficiencies in power scooters	parameter 31 "Objects produce harmful factor"	
Why?	Caused by Motor starts too fast	parameter 9 "Speed".	
Why?	The Motor control transmits the wrong voltage level	parameter 27 "Reliability"	
Why?	D/A converter transmits the wrong signal	parameter 27 "Reliability"	
Why?	Microprocessor transmits the wrong digital signal	parameter 27 "Reliability"	
Why?	Filter transmits the wrong voltage level	parameter 27 "Reliability"	
Why?	Speed adjustment potentiometer is rotated excessively and lead to wrong voltage.	parameter 33 " Difficulties of operation"	Parameter 32 "Difficulties of produce" parameter 36 "Complication of equipment"

(7) 40 Inventive Principle

Improving Parameter and Worsening Parameter are the result of the Root contradiction analysis. From 40 Inventive Principle, we can get eco-efficiency to improve negative factors of power scooter and keep our environment eternal. For example, PWM replace variable electrical impedance to save the energy, as Table 9.

Table 9 40 Inventive Principle

Engineering Parameter	Application
1 segmentation	Time segmentation: After we start power scooters, Speed adjustment potentiometer can't control speed until the soft-starter device was turned off.
10 preliminary action	Soft-starter device starts when the power was turned on. The situation of Pedal won't change the moving pace until soft-starter device was turned off. (Soft-starter device starts to protect riders.)
12 Equi-potentiality	After power scooters start, the voltage and power output of soft-starter device must maintain the same situation. (Linear Motor)
13 inversion	Take use of magnetic force effect. Take off magnets will produce break and start soft-starter device to slow the speed when accident happens. (Feedback)
19 periodic action	According to PWM, under the constant frequency, and change work cycle to make overall voltage/electric current rise or set. By this kind of intermittent switch modes to control speed and save energy.

If the elderly or the disabled ride the power scooters, they need to post a on/off magnet on the correspondence of dashboard to make the scooters start. Besides, the magnet can be used to turn off the power scooters when emergency.

Then, Microprocessor will transmits starting signal to soft starter device. Power scooters start gradually until soft starter is turned off. The elderly or the disabled can control the speed-control on the board. During this period, Speed adjustment potentiometer can't adjust the speed to bay pass.

Speed-control is made up by PWM. It can adjust speed and control speed to save energy by switching intermittently.

After improved, power scooters can avoid SUA just because rider didn't set the Speed-control to the most suitable or the lower speed in advance. We can keep the speed maintain the safety speed by using soft starter until riders get used to the speed, Fig. 10.

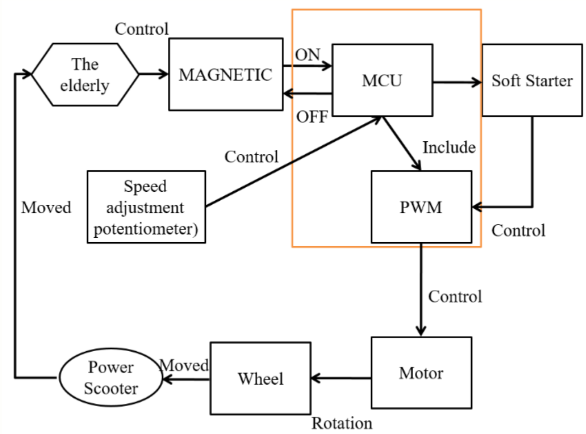


Fig. 10 Function Analysis of Inventive Principle

(8) Trimming

Solve problems which power scooters meet, delete the difficulties or convert component to achieve perfection, Table 10.

Table 10 Component to Trim

Current Carrier	Function	Object	Trimming Rule	New carrier	Trimming Problem	Method
The elderly	To revolve	Speed adjustment potentiometer	Rule E	Null	How to remove Speed adjustment potentiometer	Speed adjustment potentiometer can't be deleted.
Speed adjustment potentiometer	To control	Filter	Rule E	Null	How to remove Filter	Next statement
Filter	To control	Microprocessor	Rule A	Null	How to remove Microprocessor	No, Microprocessor is system control, it can't be cancelled.
Microprocessor	To control	D/A converter	Rule A	Null	How to remove D/A converter	Next statement
D/A converter	To control	Motor controller	Rule E	Null	How to remove Motor control	No, Motor control can't be deleted.
The elderly	To control	Speed switch	Rule A	Null	How to remove Speed switch	Next statement

Take use of Transforming function analysis to search data base, and find out transforming Mechanical energy to Electricity. By using Piezoresistive Effect to improve Speed adjustment potentiometer.

Power Scooters which are improved by Trimming, the elderly won't get hurt just because they don't set the Speed-control to the most suitable or the lower speed in advance. Besides, they don't have to stick on/off magnet. Fig. 11.

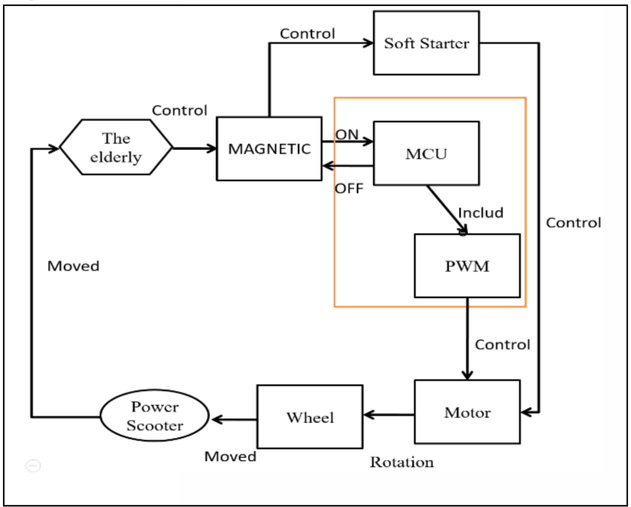


Fig. 11 Function Analysis by using Trimming

4. Benefit and Conclusion

(1) Benefit

Compare the difference among the original Patent of speed device, the Patent of Inventive Principle and the Patent of Systematic Innovative Thinking, as Table 11.

Table 11 Comparison and Difference

	The number of parts	Safety	Convenience
Original Patent	8	Low	Low
Patent of Inventive Principle	6	High	Intermediate
Patent of Systematic Innovative Thinking	5	High	High

(2) Conclusion

After comparing three patent, we can know that the patent of I of Systematic Innovative Thinking can reduce the number of parts to decrease the costs of manufacturing and repairing. It can also raise the safety and convenience when the elderly are riding power scooter and lower the medical charge caused by the accident of SUA.. In addition, we can avoid the risk of infringement and provide a new development of model for the industry.

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Systematic Innovation by User-centered Design: Case Study in Ampoule Opener Design

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Abstract

About 90.3% of nurses reported to have experienced with sharp injuries and about 37.6% of nurses oc-curred more than one time of sharp injuries by opening the glass ampoules during recent 6 months. The sharp, jagged edges formed when the ampoule neck breaks incompletely pose a serious danger to medical professionals. Literatures reviewing showed that situation of sharps injuries by opening ampoule wasn't improved yet. Further, it needed to research and solve the problem. Thus, present study developed the new ampoule opener by systematic innovation of user-centered design to avoid painful and dangerous sharps injuries. User needs analysis have been conducted from district hospital, regional hospital and medical center medical center. A questionnaire was used to survey the behaviors (tasks of opening ampoule, types of ampoules, user requirements etc.) and sharp injuries while opening glass ampoules. After analyzing pa-tents search, user needs analysis and results of questionnaire survey, present study designed and built the prototype of ampoule opener. Results of ergonomic evaluation showed that applied the ampoule opener had lower EMG activity of forearm and lower ulnar deviation on wrist. This easy-to-use multi-use am-poule opener avoids the unacceptable sharps injury rates seen when ampoules are opened by hand. The findings of this study could provide references to medical personnel in order to prevent and decrease sharp injuries as much as possible. In clinical effectiveness will be further assessed.

Keywords: Ampoule, Ergonomics, Sharp injuries, Systematic innovation

1. Introduction

The 2014 statistic data from the Taiwan EPINet (Exposure Prevention Information Network, Institute of Labor, Occupational Safety and Health) showed that the rate of needlestick and sharp injuries (NSIs) is 3.0%. However, first documented in 1983, up to 40% of all sharp injuries were not reported (Hamory, 1983). Subsequent studies have estimated the rate of under-reporting to be between 26% and 85% (Burke & Madan, 1997). Literatures review revealed that a total of 81.8% of sharp injuries were not reported, with job category significantly affecting reporting behavior. Shiao et al. (1999) surveyed 10,469 full-time medical, nursing, technical, and supporting personnel employed at 16 randomly selected hospitals from 132 available accredited teaching hospitals in Taiwan. Questionnaires were completed by 82.6% (8,645) of their samples, of whom 87.3% reported to have experienced a recent NSIs and medical staffs had the highest non-reporting rate. The epidemiology of NSIs was investigated among a complete cross-section of 1,162 nurses from a large hospital in southern Japan (Smith et al., 2006). Forty-six percent had experienced with NSIs in the previous year. Most NSIs were caused by ampoules or vials, which injured 32.3% of all nurses and accounted for 42.9% of all NSIs events. In addition, the 19,171 clinical nurses who came from 229 hospitals in 23 sites in China recalled the sharp injuries in past year. The 81.4% of nurses had sustained at least one sharp injury. The broken glass injuries accounted 38.3%. There are 49.7% of injuries occurred during "using the sharps" (Wang et al., 2009). Cheung et al. (2010) reported that there were a total of 51 reported cases of NSIs from Hong Kong. The annual prevalence of NSIs in four academic years from 2002-2003 to 2005-2006 ranged from 0.6 to 1.6 cases while the incidence rate was one new case per 100 nursing students per academic year. Broken glass from opening ampoules (62.50%) was responsible for most sharp injuries. Further, Chiu et al. (2011) investigated sharp injuries from January 2007 to March 2009. The

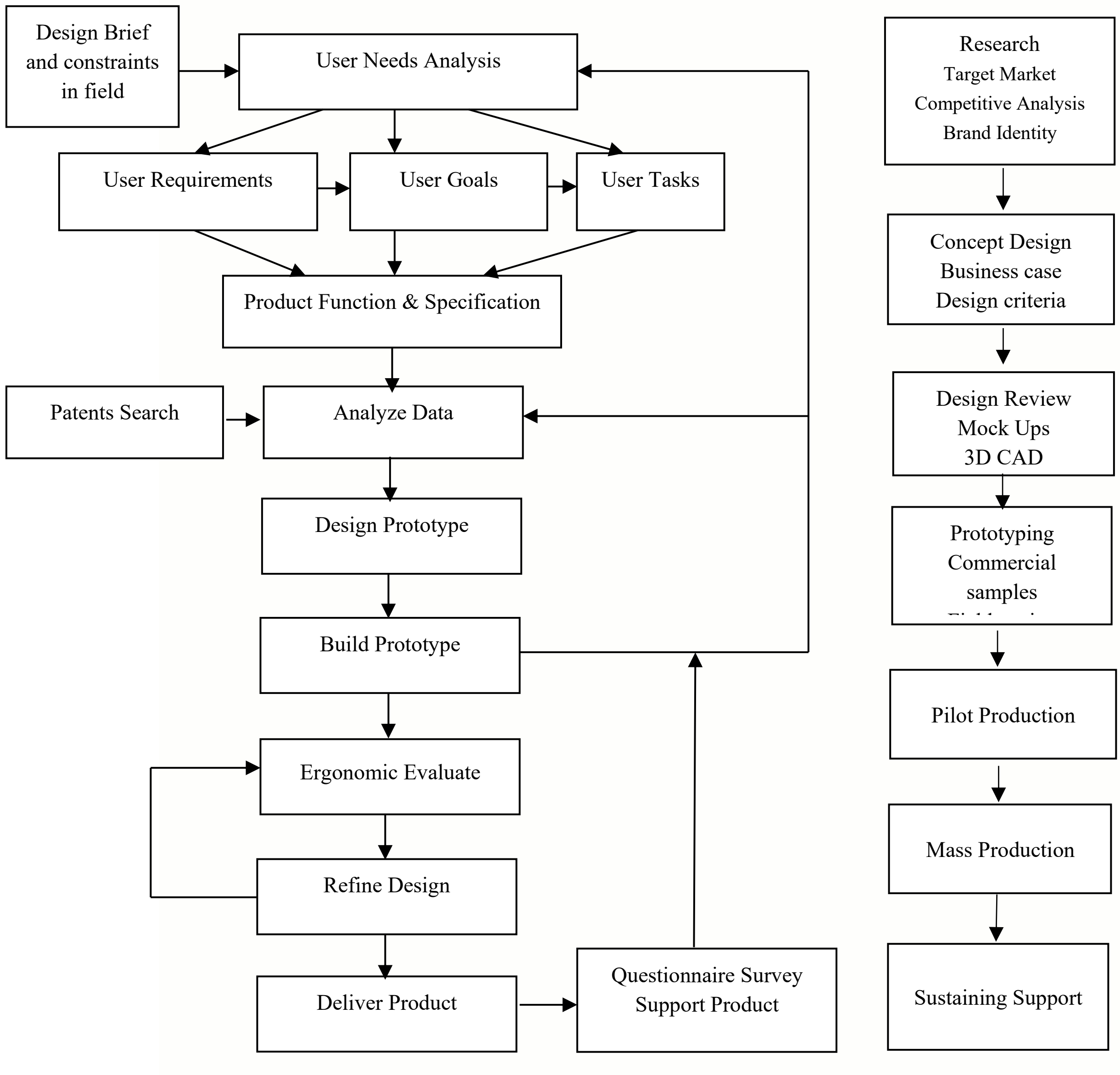
165 cases revealed that 53.9% occurred mostly in ordinary ward. The main injury site is index finger (70.9%), and the depth located on superficial skin with bleeding (72.1%). Voide et al. (2012) also reported that about 9.7% of health workers had sustained at least one NSIs during the preceding twelve months. The NSIs were more frequent among nurses (49.2%) and doctors performing invasive procedures (36.9%). Yu et al. (2014) reported that the occurrence rate of sharp injuries was 70.4% among 189 nursing staffs and the nursing staffs with shorter working time, lower education had more sharps injuries (averaged 2-5 times) in Xinjiang. A study of nurse sharp injuries was conducted in the department of sterile supply in Chengdu. A total of 88 injuries cases found with an average of 2.7 times each person (Zhang et al., 2014). About 90.3% of nurses reported to have experienced the sharp injuries and about 37.6% of nurses occurred more than one time sharp injuries by opening the glass ampoules during recent 6 months (Lien et al., 2016). From the results of literatures reviewing indicates that the situation of sharps injuries by opening ampoule wasn't improved yet. It needed to research and solve the problem. Thus, present study want to develop the new ampoule opener by systematic innovation of user-centered design to avoid painful and dangerous sharps injuries.

Engineering is concerned with improving products from the point of view of mechanical and electrical design, and human factors and ergonomics are concerned with adapting products to people, based upon their physiological and psychological capacities and limitations, the objective being to improve overall system performance (involving human and product elements). Present study integrated both engineering and human factors/ergonomics. New product development could be incorporation of the user requirements, user goals and user tasks into the design of a product and will only be realized through a user-centered design process in first time. In present study provided the systematic innovation by user-centered design: case study in ampoule opener design. An ampoule is a small sealed vial which is used to contain and preserve a sample Ampoules are most commonly used to contain pharmaceuticals and chemicals that must be protected from air and contaminants. Ampoules are commonly made of glass. Majority of nurses reported to have experienced the sharp injuries and about 37.6% of nurses occurred more than one time sharp injuries by opening the glass ampoules during recent 6 months. The sharp, jagged edges formed when the ampoule neck breaks incompletely pose a serious danger to medical professionals. Fingers and hands can be cut from the sharp jagged edge formed where the neck breaks. Ampoule related injuries are frequent and dangerous Thus, this project developed the new ampoule opener by systematic innovation by user-centered design to avoid painful and dangerous sharps injuries.

2. Methods

Incorporation of the user requirements, user goals and user tasks into the design of a product will only be realized through a user-centered design process as illustrated in Figure 1. Given that user activity is central to design, this information needs to be captured and incorporated into the design process. Design may start with a design brief specified by the client organization. The user-centered approach would start the design activities with methods aimed at capturing user needs. These needs, together with the functional specification and the constraints will be formulated into the system specification. Additional constraints might include the cost and weight of materials and the size of components. From this a prototype may be built and tested. The resultant data may be used to inform the design team. This could lead to a complete overhaul of the system specification (reversing the design process back to a re-analysis of the user needs), or modification of the prototype, or minor refinements in the design. After build prototype, ergonomic evaluation have been conducted for new ampoule opener. There may be many feedback loops around this process, or some stages may be omitted owing to resource constraints. Finally the product and associated materials (such as instructions, packaging and marketing) are delivered. Depending upon the life of the product, it may have to be supported by production of spares, maintenance contracts and helplines. Whilst this description represents a sanitized version of the design process, it does begin to touch on some of the complexity involved in design. This complexity is exacerbated when one appreciates the number of people who have a stake in product design, including the designers, ergonomists, accountants, management, technicians and engineers. If this group is not working harmoniously, agreement on the design solution is not likely to be forthcoming. At the early stages of design there may be as many as ten concepts for the product. This may lead to, say, three proposals which are narrowed down to one product. The process of freezing a range of concepts into a single solution makes it clear why human factors needs to get into the process as early as possible, as this is when most change can be made at least cost to the design process (Stanton, 1998).

New product development of traditional researching system involved the research (target market analysis competitive analysis, brand identity, concept design (business case, design criteria), design review (mock up, 3D CAD), prototyping (commercial samples, field testing), pilot production, mass production and sustaining support. By contrast, present study applied the user-centered approach that would start the design activities with methods aimed at capturing user needs. Compared the two new product development stages presented in Figure 1. The research model focuses on user needs analysis, patents search and ergonomic evaluation.



(a) user-centered design approach (b) traditional researching system

Fig. 1 Systematic innovation by user-centered design (a) and traditional researching system (b)

3. Results

3.1 User needs analysis

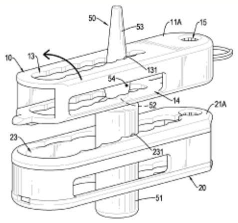
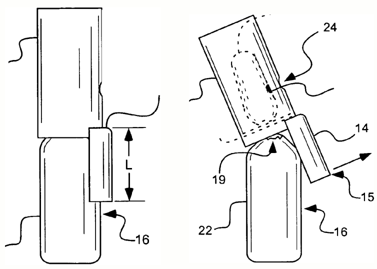
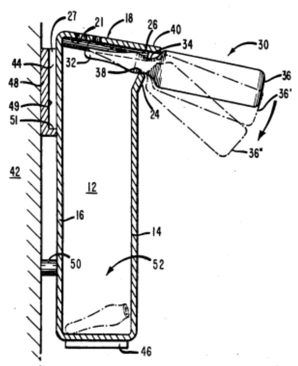
In present study the user needs analysis have been conducted from district hospital, regional hospital and medical center. A questionnaire was used to survey the behaviors (tasks of opening ampoule, types of ampoules, user requirements etc.) and sharp injuries while opening glass ampoules. A total of 300 questionnaires were dispatched to hospitals, with a response rate of 86% (n = 258). Nurses are sampling from district hospital (24%), regional hospital (14.3%) and medical center (61.6%). We collected the user needs analysis and design brief/constraints in field to develop the new product function and specification. A questionnaire was used to survey the behaviors and sharp injuries while opening glass ampoules. Results of analysis showed the socio-demographic characteristics of respondents by gender, age, education level, job category, hospital category and years of service. Majority of nurses are female (98.1%). Age distribution of the respondents is 36.4% (less than 29 years old), 44.2% (30-39 years old) and 19.4% (more than 39 years old). Majority of nurses (81.8%) had college degree. The years of service involved the 10.9% (< 1 year), 10.5% (1-2 years), 14.7% (3-5 years), 21.3% (6-9 years) and 42.6% (> 10 years). Among the 258 respondents are professional nurse (63.6%), followed by nurse (30.6%), and head nurse (5.8%). Nurses are sampling from district hospital (24%), regional hospital (14.3%) and medical center (61.6%). About 46.9%, 23.6% and 29.5% of respondents are in medicine department, surgery department and others, respectively.

Results of analysis showed that about 90.3% of nurses reported to have experienced the sharp injuries and about 37.6% of nurses occurred more than one time sharp injuries by opening the glass ampoules during recent 6 months. There are 43% nurses by hand, 40.3% nurses by hand with alcohol pad, and only 16.7% nurses by tools while opening glass ampoule. The main causes of sharp injuries are opening ampoule, drawing medication from an ampoule, and handling sharps collection. Further, main cause of sharp injuries is improper force to crush glass ampoule. Only 11.6% nurses could report to head nurse and about 63.6% nurses affected the work. About 88.8% of nurses want to use the ampoule opener and about 56.6% of nurses want to buy it while ampoule opener costs less than NT$100 (US$ 3).

3.2 Patents search and analysis

Patents search applied by Orbit Intelligence System (Questel, France). Totaled 1384 patent families had found for searching “ampoule opener or ampoule opening or ampoule breaking or ampule bottle opener or ampule opener”. Results of search patents showed that the main key technology concepts involved ampoules (22.4%), ampoule opening (12.6%), ampoule breaking (8.8%), ampoule neck (7.9%) and grinding wheel (7.2%). Main International Patent Classification (IPC) are B67B-007/92 (by breaking, e.g. for ampoules), B67B-007/46 (cutting devices, i.e. devices including at least one cutting element having one or more cutting edges for piercing through the wall of a closed container, e.g. can openers), B67B-007/54 (sweep cutter type, i.e. an opening device including means to establish a pivot point between the cutting element and the container and having means to move the cutting element about the pivot point), B67B-007/44 (combination tools, e.g. comprising cork-screws, can piercers, crown-cap removers), A61J-001/06 (ampoules or cartridges) and A61M-001/00 (Suction or pumping devices for medical purposes; Devices for carrying-off, for treatment of, or for carrying-over, body-liquids; Drainage systems). These data could be considered in further design of new ampoule opener. For example, three patents of ampoule opener showed in Table 1.

Table 1 Patents of ampoule opener.

Inventors, Patent name, Patent number and IPC codes	Abstract	Brief description of the drawings
Liu et al. (2015) Ampoule opener US8973800 B67B-007/92; B67B-007/44	An ampoule opener has an opening unit and a cover unit. The opening unit is a rigid frame and has two panels, two head-clamping holes and two pairs of wave-shaped flanges. The panels are respectively an upper panel and a lower panel. The head-clamping holes are elongated in length and tapered in width and are respectively formed through the panels. The pairs of wave-shaped flanges are formed between the panels and the head-clamping holes. The cover unit is flexible, is detachably mounted around the opening unit and has two covering boards, a mounting recess, two body-clamping holes and two pairs of wave-shaped edges. The body-clamping holes are elongated in length and tapered in width and are respectively formed through the mounting boards and communicate with the mounting recess. The pairs of wave-shaped edges are formed between the mounting boards and the body-clamping holes.	
Wiley & Halvorson (2011) Ampoule opener and associated methods US7,946,461 B67B-007/92; B62F-003/00	An ampoule opener comprises a receiving body sized to accommodate a cap portion of an ampoule and a shield extending from the receiving body and being configured to lie adjacent a medicament storing portion of the ampoule when the cap portion of the ampoule is accommodated within the receiving body. The shield is rigidly related to the receiving body so as to be more resistive to bending relative to the receiving body in a direction away from a longitudinal axis of the receiving body than toward the longitudinal axis of the receiving body.	
Caron (1983) Ampoule opener US4,405,067 B26F-003/00	An ampoule opener for safely and conveniently breaking the tips off elongated ampoules of varying sizes to make possible the extraction of the contents therefrom. The opener includes a housing having an opening formed on the front face thereof for insertion of an ampoule tip there through. A projection extending outwardly from the front face is disposed adjacent a lower edge of the opening and serves as a fulcrum upon which the ampoule neck is placed and about which torque is applied to snap off the ampoule tip at the neck when the end of the tip engages an internal bearing surface. A hood over the housing opening protects the user from any spray resulting from the breaking of the ampoule and an internal cavity collects the tips broken from the ampoules.	

3.3 Design Prototype

After analyzing patents search, user needs analysis and results of questionnaire survey, we are developing the prototype of ampoule opener. Furthermore, present study designed the new type ampoule opener with a clamping element and a cylindrical sleeve element (Taiwan Patent No. M489643; US Patent application No. US20160046474). An ampoule opener is provided. The ampoule opener includes a clamping element and a cylindrical sleeve element. The clamping element includes a plurality of clamping arms. Each one of the plurality of clamping arms includes a clamping terminal. The cylindrical sleeve element is disposed around the clamping element. The cylindrical sleeve element is adapted to move back and forth along the clamping arms thereby adjusting an interval of each two adjacent clamping terminals. The ampoule opener is capable of breaking off ampoules with various calibers due to that the interval between the clamping terminals can be adjusted by moving the cylindrical sleeve element. (Figure 2).

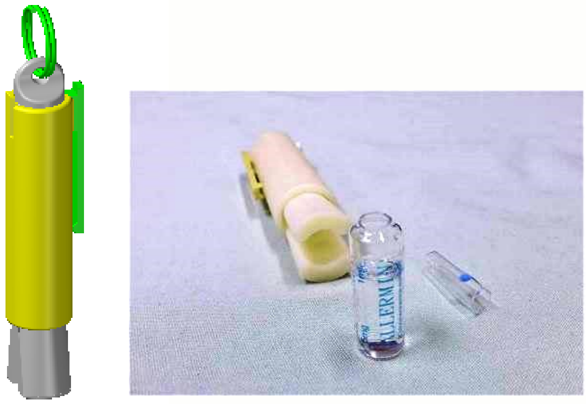


Fig. 2 The new ampoule opener design and prototype.

3.4 Ergonomic evaluation

An ergonomic evaluation was examined the forearm muscle activities, and wrist postures for the two methods of opening glass ampoule. Five nurses were recruited in present study. All subjects were healthy and reported no musculoskeletal problems that might influence performance detrimentally. Each participant performed the two methods of opening the glass ampoule for three repetitions, respectively (Figure 3). The experimental empty 5 ml ampoules made by GL Glass Company (Hsinchu, Taiwan). The Electromyography (EMG) activities of the pronator teres muscle groups and wrist postures were recorded by Biometric data acquisition system (DataLog MWX8, Biometric Ltd., UK).

All data were coded and summarized using SPSS 21.0 software for Windows. In ergonomic evaluation, the dependent variables were angles of wrist, and EMG (%) for Pronator Teres. Further, analysis of variance (ANOVA) was utilized to identify significant differences between conditions for dependent variables. Statistical significance was set at a probability level of 0.05.

Results of ergonomic evaluation showed that EMG of right hand was significant difference between opening methods (Figure 4). The right forearm muscle activities were significant lower while using the ampoule opener (44.14% MVC). However, the higher muscle activities were found while opening ampoule by hand (54.72% MVC). On the other hand, there were not significant differences in EMG of left hand between opening methods, because the main function of left hand is holding the ampoule bottle. Table 2 presented the wrist postures for dorsiflexion and ulnar deviation while opening the glass ampoule by hand and two types of ampoule opener. There are not significant differences in dorsiflexion and ulnar deviation of left hand between methods of opening ampoule. By contrast, lower mean dorsiflexion of right hand was found in applied the ampoule openers.

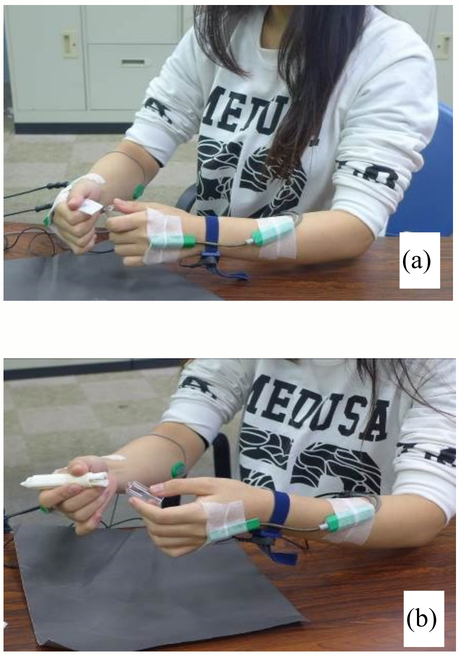


Fig. 3 Ergonomic evaluation for opening the glass ampoule by two methods ((a) by hand; (b) by ampoule opener)

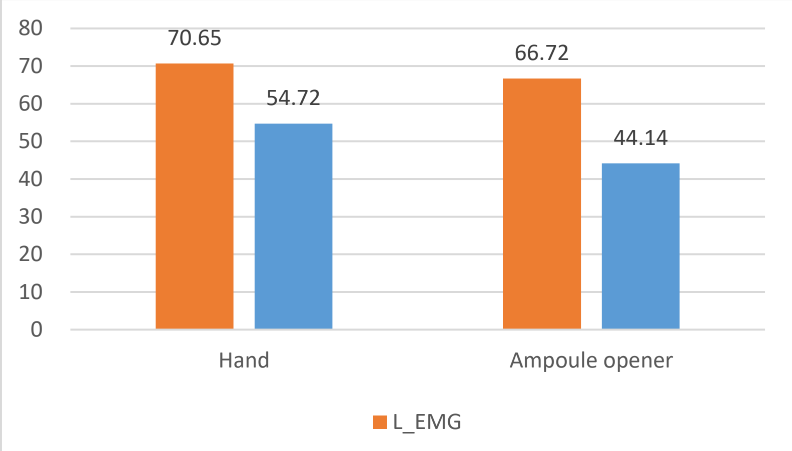


Fig. 4 Electromyography of the pronator teres for opening the glass ampoule by two methods

Table 2 The dorsiflexion and ulnar deviation between methods of opening ampoule

Methods of opening ampoule	Left hand		Right hand	
	Dorsiflexion	Ulnar deviation	Dorsiflexion	Ulnar deviation
Hand	25.52	19.61	24.26	17.71
Ampoule opener	23.21	17.15	19.42	19.46

4. Conclusion

The hospitals did not provide the appropriate tools to the nurses for opening the glass ampoule. Situation of sharps injuries by opening ampoule wasn't improved yet and needed to research and solve the problem. Thus, present study want to develop the new ampoule opener by systematic innovation of user-centered design to avoid painful and dangerous sharps injuries. Incorporation of the user requirements, user goals and user tasks into the design of a product will only be realized through a user-centered design process. Present study provided the new ampoule opener design with a clamping element and a cylindrical sleeve element. The new ampoule opener is capable of breaking off bottles with different calibers of ampoule. After ergonomic evaluation showed that the new ampoule opener had lower EMG activity of forearm and lower ulnar deviation and dorsiflexion on wrist. This ampoule opener can avoid painful and dangerous sharps injuries. For an example of existing tool (SnapIT™, Qlicksmart Ltd. Co., Australia) costs from AUD 33.3 to 41.9 (NTD 513 to 964). Further, users need to select the appropriate tool size for different ampoule sizes. e.g., Regular size is for 1ml to 15ml and large size is for 5ml to 25ml. It is not convenient for using. Thus, the new ampoule opener in this study could be compatible ampoule sizes from 1ml to 20ml and be more convenient, safer, cheaper avoiding the injury. This easy-to-use multi-use ampoule opener avoids the unacceptable sharps injury rates seen when ampoules are opened by hand. About 88.8% nurses want to use the ampoule opener. In clinical effectiveness will be further assessed.

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