Forecasting technology trends based on separation of product inventions and process inventions: The dominant design

Koji Masuda¹, Shigeyuki Haruyama²
1 Graduate School of Science and Technology for Innovation, Yamaguchi University
2-16-1 Tokiwadai, Ube-shi, Yamaguchi, 755-8611, Japan
Email: a006wcu@yamaguchi-u.ac.jp

2 Graduate School of Innovation and Technology Management, Yamaguchi University
2-16-1 Tokiwadai, Ube-shi, Yamaguchi, 755-8611, Japan
Email: haruyama@yamaguchi-u.ac.jp

Abstract. This study examines whether the A-U model can be visualized prospectively and whether the emergence of a dominant design can be forecasted. Companies are required to create innovation to fulfill their roles in sustainable growth. An accurate understanding of market and technology trends is essential to set up research projects and develop competitive strategies. To clarify the technology trends, inventions are segregated into product inventions and process inventions as a pre-processing step for patent analysis, product values are extracted, and core technology groups are separated. It is observed that the transition from product innovation to process innovation has already occurred for projectors where the market has already been formed and a dominant design has emerged.

Keywords: S-curve, A-U model, patent analysis, technology trend, dominant design

1. Introduction
As members of society, companies are required to create innovation to fulfill their roles in sustainable growth. Stokes categorized the motivations for the research into four categories [1]. To create innovation, the research projects that corporate research and development (R&D) should set up are in the YES area of the ‘Consideration of use?’ axis. However, companies face the difficulty of establishing such research projects. In this era of volatility, uncertainty, complexity, and ambiguity (VUCA), customer needs are more diverse and the pace of change is faster and more uncertain; moreover, some markets are saturated, and some products are mature. In Ansoff’s growth matrix [2], the issue for companies today is how to develop a growth strategy for new markets and new products while expanding the current business areas in which they already compete, such as globalization. To solve this problem, an accurate understanding of the situation is essential.

In other words, it is necessary to clarify the market trends and technology trends. The visualization of market trends will allow a company to deliver products to the market in a timely manner that meets customers’ needs. The visualization of technology trends will allow the company to be ahead of its competitors in establishing research projects and to connect technology development and product development effectively and efficiently. By understanding customers, markets, and technology, a company will be able to formulate and implement strategies that help it stay competitive. As a result, it is believed that innovation can be created.

The relationship between the keywords ‘customer value-product-process’, ‘core technology’, ‘invention’ and ‘innovation’ that are discussed in this study is shown in Figure 1. ‘Customer value’
is the market’s demand and the various values, including the fundamental value, that the customer experiences and accepts. ‘Product’ is a product that provides ‘customer value’. In addition, ‘process’ is a process of producing a ‘product’. The distinctive technology that differentiates a product is the ‘core technology’, which is included in the products and manufacturing processes. According to Article 2(3) of the Japanese Patent Act, ‘invention’ is defined as ‘an invention of a product’ or ‘an invention of a process’, and ‘an invention of a process’ is defined as ‘an invention of a process for producing a product’ or ‘an invention of any other process’. ‘Product innovation’ and ‘process innovation’ are the innovation classifications presented by the A-U model described below.

Figure 1. Relationship between the keywords

To clarify technology trends, two ideas are focused on: the technology S-curve and the A-U model. The technology S-curve argues that technology evolves in an S-shape and eventually becomes saturated. This S-curve represents the state of technology evolution. The Abernathy and Utterback (A-U) model has been perfected through three studies and has had a significant impact on innovation research. In the A-U model, innovation is divided into product innovation and process innovation, and the state of occurrence of each innovation is represented.

In addition, it is argued that a dominant design will emerge during the transition from product innovation to process innovation. In addition, the authors present efficient management methods for technology and organizations in fluid, transition, and specific patterns to increase the probability of success of an innovation.

In our previous study, we showed that the S-curve of a technology can be drawn prospectively by separating inventions into ‘product inventions’ and ‘process inventions’ as a preprocessing step for patent analysis. Furthermore, in the ‘technology’ layer, the A-U model’s idea of ‘the shift from product innovation to process innovation’ was estimated. In this study, based on
the results of our previous research, we discuss the A-U model, especially the dominant design, in the ‘market’ layer using patent analysis. Patent information is used in the analysis of the states of occurrence of product innovation and process innovation, as well as the transition period, i.e., the emergence of a dominant design, as indicated by the A-U model [10]. This study focused on the core technologies of Japanese monozukuri companies and recognized the emergence of a dominant design from the variation between product innovation and process innovation using the F term of the Japanese patent classification. This is an example of a case where the core technology is known. The application of the quality function deployment (QFD) method is proposed to identify the core technology [11]. This method uses customer requirements as a starting point and utilizes a company's internal resources. Therefore, the use of this method is limited. Furthermore, a method is proposed to extract the core patents from the citation information analysis of patents and derive the core technology using text mining [12]. However, it is a technical and complex method.

The layers of the market are the customer value and products (including how the products are manufactured). The value of a product (manufacturing method) that achieves customer value is the focus of attention. If patent analysis utilizing published patents is able to extract patents that contain product value, the inventions contained in those patents are the distinctive technologies that differentiate the product, i.e., the core technologies. Patent analysis is useful for visualizing technology trends [13,14]. Assume that a product is manufactured using the technology contained in a patent-pending invention. To satisfy the customer, the product is introduced to the market. Therefore, patent analysis allows us to predict the future of technologies and markets. However, it goes without saying that the analysis using the patent filing dates produces faster results than using the market trend over time.

In this paper, to investigate technological trends, inventions are segregated into product inventions and process inventions as a pre-processing step for patent analysis. Focusing on the product value and core technologies at the market layer, we examine whether the technology S-curves and the A-U models can be visualized prospectively and whether the emergence of dominant designs can be predicted. A projector was selected as the example product for the verification. This is because the market for projectors fits the scope of this study according to the following three reasons:

- A market has already been formed. In other words, products are launched, product value and core technologies exist, and a dominant design has emerged.
- There is still room for expansion in the current business field.
- Growth strategies for new markets and new products are expected.

2. Research methodology

Japanese published patents that have been applied for since 1980 were used in the analysis. The theme code, one of Japan's original patent classifications, was used to search for the patents on projectors. Patents are subdivided using File Indexes (FIs). In contrast to the IPC, which is a universal patent classification, the Japanese FIs are subdivided into approximately 190,000 items compared to the IPC's 70,000 items, and all the technical fields defined by the FI are divided into certain technical areas called themes. The themes are given 5-digit alphanumeric theme codes. Thus, IPC and theme codes are indirectly related to each other via the FIs that subdivide IPCs.
The analysis flow in this study is shown in Figure 2. First, a search for patents on projectors is performed, and the population is extracted. The next step is pre-processing. The thick boxed area, including the pre-processing, is the same as in our previous study [9]. The product value is then extracted from each of the sub-populations created by the pre-processing and each sub-population is segregated into groups related to the core technology. After that, this process is performed for each of the core technology groups. In this paper, the states of occurrence of product innovation and process innovation are depicted as the main processing.

In terms of product value extraction, a method for extracting a product’s value from a sub-population using text mining is proposed. The results from text mining are then segregated into a population of published patents related to the core technology associated with the product’s value. The flow of product value extraction is shown in Figure 3. We use MeCab [15], a Japanese morphological analysis software, to perform text mining on Japanese patents, decompose the patents into words and phrases and tabulate the words and phrases by their frequencies. Unlike Western languages, Japanese text information cannot be handled ‘without word segmentation’.
consisting of a series of words and phrases. It is necessary to decompose Japanese text information into elemental detections corresponding to morphemes and perform morphological analysis to identify the grammatical attributes such as parts of speech and conjugations [16].

First, morphological analysis is performed on the 'abstract of the disclosure' of the published patent applications in the sub-population, and a noun phrase and/or verb phrase is extracted for each patent application. Then, for each leading FI, the noun phrase and/or verb phrase is ranked and compared with the ranks of the other leading FIs. Common noun phrases and/or verb phrases and characteristic noun phrases and/or verb phrases are then extracted. The common noun phrases and/or verb phrases are the noun phrases and/or verbs that frequently occur together even when the FIs are different, i.e., in different technology categories. In other words, they are considered to be words that express the basic common value of a product. Conversely, the characteristic noun phrases and/or verb phrases are included only in the leading FI and not in the other leading FIs. In other words, they are words that express the value of a product that does not exist in any other technology category. This characteristic noun phrase and/or verb phrase is the product value phrase. Noun phrases and verb phrases are used in this paper because it was judged that a noun phrase for a 'product' and a combination of a noun phrase and a verb phrase for a 'process' are appropriate as the parts of speech for a 'product' and a 'process', respectively, to express the value of a product. Then, for each lead FI, a group of published patent applications, i.e., a core technology group, is separated in the 'abstract of the disclosure', which contains a phrase indicating the product value, of the invention in the published patent application.

3. Product value
The theme code for the projector is 2K203, and the population size of published patent applications in this analysis is approximately 31,700. As shown in our previous study [9], the projector population was pre-processed and separated into two sub-populations. Then, for each of the two sub-populations, 'product inventions' and 'process inventions', the leading FIs were ranked and separated into groups based on the top four leading FIs in each group. Morphological analysis is performed on the 'abstract of the disclosure' in the published patent applications. After removing noisy patent-specific words and numbers, the noun phrases and/or verb phrases are ranked in order of their frequency of occurrence. Then, the common noun phrases and/or verb phrases and the characteristic noun phrases and/or verb phrases were extracted by comparing them with those of other leading FIs. Table 1 shows the noun and verb phrases common to the four leading FIs for 'process inventions'. The noun phrases in Table 1 are also common to the four leading FIs in 'product inventions'. These are the basic functions of projectors, such as 'input image signals', 'project images', 'equip a screen', and 'provide a projector'. Therefore, it is conceivable that these words are common to all the leading FI groups.

<table>
<thead>
<tr>
<th>Noun phrases</th>
<th>Verb phrases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image signals, video signals, image data</td>
<td>input, obtain</td>
</tr>
<tr>
<td>image, video, projection image, image capture</td>
<td>project, display, generate, output</td>
</tr>
<tr>
<td>screen, projection surface</td>
<td>equip</td>
</tr>
<tr>
<td>projector, projection system, projection equipment</td>
<td>provide</td>
</tr>
</tbody>
</table>
Table 2. Characteristic keywords of ‘process inventions’

<table>
<thead>
<tr>
<th>Noun phrases</th>
<th>distance</th>
<th>projection</th>
<th>system</th>
<th>location</th>
<th>object</th>
<th>distortion</th>
<th>shape</th>
<th>correlation</th>
<th>relation</th>
<th>projection</th>
<th>region</th>
<th>light</th>
<th>image</th>
<th>light source</th>
<th>brightness</th>
<th>motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>G03B21/00,D</td>
<td>12</td>
<td>16</td>
<td>-</td>
<td>-</td>
<td>29</td>
<td>27</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>24</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H04N5/74,Z</td>
<td>-</td>
<td>-</td>
<td>24</td>
<td>25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>H04N5/74,D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12</td>
<td>18</td>
<td>19</td>
<td>21</td>
<td>25</td>
<td>27</td>
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<td>-</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>G03B21/14,Z</td>
<td>21</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>13</td>
<td>18</td>
<td>26</td>
<td>29</td>
<td>-</td>
</tr>
</tbody>
</table>

Conversely, Table 2 shows the noun phrases for ‘process inventions’ that are characteristic of a certain leading FI group, i.e., contained in only one or two leading FI groups. The numbers in the table are the ranking positions of the keywords in each FI, where '-' means that the keyword is not included in the 30th ranking. These keywords are the most important keywords in each group according to the leading FI because of their high frequency of occurrence rankings and the characteristics in each group according to the leading FI. Similarly, the characteristic keywords for the verb phrase ‘process inventions’ and the noun phrase ‘product inventions’ were also extracted. Table 3 shows the main product values, selected from the characteristic keywords, of each group of the leading FIs. These are the configurations and functions that differentiate the products and are represented by the ‘core technology’ for each FI. From each group according to the leading FI, the groups of published patent applications whose characteristic keywords shown in Table 2 are included in the ‘abstract of the disclosure’, i.e., the core technology groups, are separated.

Table 3. Product value of each group of the leading FIs

<table>
<thead>
<tr>
<th>Product innovations</th>
<th>G02F1/13,505</th>
<th>liquid crystal panel, LCD projector, light bulb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G03B21/14,A</td>
<td>light source device, excitation light, fluorescent substance</td>
</tr>
<tr>
<td></td>
<td>G03B21/00,D</td>
<td>projection lens</td>
</tr>
<tr>
<td></td>
<td>G03B21/14,Z</td>
<td>optical modulator</td>
</tr>
<tr>
<td>Process innovations</td>
<td>G03B21/00,D</td>
<td>distance / measure</td>
</tr>
<tr>
<td></td>
<td>H04N5/74,Z</td>
<td>location, object / determine</td>
</tr>
<tr>
<td></td>
<td>H04N5/74,D</td>
<td>distortion, shape, correlation / reduce</td>
</tr>
<tr>
<td></td>
<td>G03B21/14,Z</td>
<td>light image / focus</td>
</tr>
</tbody>
</table>

Figures 4 and 5 show the cumulative numbers of published patent applications in the core technology groups segregated for ‘product inventions’ and ‘process inventions’, respectively. Regarding Figure 4, first, in terms of the rise time, the 1st FI, G02F1/13,505, and the 3rd FI, G03B21/00,D, are approximately 1988-1989 and the 2nd FI, G03B21/14,A, and the 4th FI, G03B21/14, Z, are approximately 2003-2004, which represents an approximately 15-year gap. Next, in terms of the shape of the S-curve, the slope of the S-curve has increased after a certain year for all FIs. Specifically, when comparing the numbers before and after the five-year average rate of increase for a certain year, G02F1/13,505 has increased by approximately three times since 1999, G03B21/14, A has increased by approximately three times since 2009, G03B21/00, D has increased by approximately eight times since 2002, and G03B21/14, Z has increased by approximately three times since 2010. Regarding G02F1/13,505 and G03B21/00,D, the curves are
saturated in 2005 and 2010, respectively; meanwhile, the slope of the 4th FI, G03B21/14,Z, has decreased since 2016, and the stage has been moving from maturity to saturation.

Figure 4. Cumulative number of core technology groups for product inventions

Regarding Figure 5, first, in terms of the rise time, the 1st FI, G03B21/00,D is 2002; the 2nd FI, H04N5/74,Z is 2006; the 3rd FI, H04N5/74,D is 2005; and the 4th FI, G03B21/14,Z is 2009. Next, in terms of the shape of the S-curve, G03B21/00,D and G03B21/14,Z show different tendencies from other FIs, including ‘product inventions’. The slope of the S-curve decreased after a certain year. However, the slopes of H04N5/74,Z and H04N5/74,D increased after a certain year. Specifically, when comparing the numbers before and after the four-year average rate of increase for a certain year, G03B21/00,D has decreased by approximately 0.4 times since 2006; H04N5/74,Z has increased by approximately three times since 2011; H04N5/74,D has increased by approximately 1.5 times since 2012; and G03B21/14,Z has decreased by approximately 0.8 times since 2014. For G03B21/00, D, the curves are saturated in 2010; and for H04N5/74, Z, the slope of the curve has decreased since 2016, and the stage has been moving from maturity to saturation.

Figure 5. Cumulative number of core technology groups for process inventions
4. The A-U model and the dominant design

Figure 6 depicts the state of innovation shown by the A-U model using the normalized number of published patents as the vertical axis, adding the four core technology groups for each of the 'product inventions' and 'process inventions'. Product innovations had a rise time in the late 1980s and peaked in 2003 after an increase. After that, it decreased and is now almost unchanged. Conversely, process innovations had a rise time in 2000, peaked in approximately 2013 and are currently declining. This figure shows that the state of innovation tends to show a transition from product innovation to process innovation.

If the timing of the emergence of a dominant design is defined as a decrease in the rate of product innovation and an increase in the rate of process innovation, the timing of the emergence of a dominant design can be observed at approximately 2004. In fact, the peak of the global market for projectors was approximately 2013-2014. Generally, a product is introduced to the market after a patent application is filed. From there, the market grows and matures. On this premise, a correlation can be found between the timing of the emergence of the dominant design in Figure 6 (approximately 2004) and its peak timing in the market (2013-2014).

The trends of the core technologies for product and process technologies and the states of product innovation and process innovation can be analysed and visualized using the patent information, and the results may provide suggestions for setting up research projects in corporate R&D, especially from the product and process perspectives. From the S-curves shown in Figures 4 and 5 and the A-U model shown in Figure 6, we consider a practical example to establish a research project for the projector. To further improve the quality, cost, and delivery (QCD), there will be research projects conducted to acquire process technologies that will lead to process innovation in a short period of time. As a growth strategy, market development using existing products with improved QCDs, as referred to in Ansoff's growth matrix, may be an option.

![Figure 6. Situation of product innovation and process innovation](image)

5. Conclusion

As a pre-processing step for the patent analysis, a method to separate inventions according to their 'product' and 'process' aspects is used. The product value was extracted, and the sub-populations were separated into core technology groups so that the technology S-curves and A-U models could be prospectively drawn for the layers of the market. It was observed that the transition from product innovation to process innovation has already occurred in the projectors market since the market has already been formed, and a dominant design has emerged.
Considering what is commonly referred to as the transition time between patent applications and product launch to growth and maturity, the timing of the emergence of the dominant design derived in this analysis is appropriate. However, it remains to be determined when the dominant design actually emerged as a product by using other methods such as product market analysis. The forecast of the technology trends visualized by our method, i.e., a dominant design has already emerged and the peak of process innovation has already passed, will provide great guidance for establishing corporate R&D projects.

6. Acknowledgement
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7. References