Innovation Position: A Quantitative Analysis to Evaluate the Efficiency of Research & Development on the basis of Patent Data

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Abstract

Using patent data, we propose a new quantitative analysis to investigate the integration type and degree of leading edge technologies in order to examine the research & development (R&D) status, efficiency and strategies of companies. Defining three types of categorization based on IPC (International Patent Classification) and CO-IPC of patents, the concept of "innovation position" is introduced.

Focusing in the Japanese patents concerning "fuel cell batteries", it is shown that the progress status of R&D in various industrial sectors and also the differences of companies' core competences are reflected in innovation positions. Furthermore, by utilizing F terms, that are Japanese unique patent classification codes supplementing IPC, the characteristics and strong points of companies even in similar innovation positions are shown to be highlighted from technological viewpoint. Our approach shed brighter light on further comprehension of technological linkages and innovation.

1. Introduction

Recently, innovation is considered to be one of the most important key drivers for modern corporate management, since it is imperative to continue improving and creating corporate value. It is mentioned that not only the research activities in enterprises but also those in universities and national research institutes have been playing an important role in inducing innovation to enhance competitiveness of firms since the enactment of the Bayh-Dole Act ([1], [2], [3]). Under such circumstances, integration of technological elements in various leading technologies such as nanotechnology, Micro-Electro-Mechanical Systems (MEMS), robotics, oil alternative energies, biotechnology and information and telecommunications, is regarded as one of the most efficient means to generate innovations. Utilizing technologies and knowledge in different research fields, this integration approach is expected to overcome technological obstacles in a single field of technology, and promote the wide usage of research results in markets.

From a global competitiveness point of view, it is of critical importance for enterprises to obtain patents on leading inventions in advanced technological fields [4]. Firms holding an important number of patents in a new technological field are either able to monopolize the new business based on patented technologies or carry business to their advantage by levying a patent fee to other companies intending to join the new market. In Japan, national strategic council on intellectual property published "outline for intellectual property strategy" in 2002, and nowadays, a large number of industrial enterprises are promoting R&D by putting emphasis on patent application, particularly in other countries [5].

In general, it takes three to five years for the results of a research based on the integration of advanced technologies to come in the shape of a product to the public. Meanwhile, it is effective to examine these researches and assess their impacts on the creation of innovation by an appropriate quantitative approach. Especially, by analyzing how companies deal with those researches, we are able to forecast which technological fields and areas will provide a superior competitive edge internationally. However, grasping the reality of R&D in advanced technologies, expected to be seeds of

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future company profits, is quite difficult because of its high confidentiality. Therefore, the analysis has to be based on data available for everyone, such as patent information and R&D investments.

Using patent application data, this paper introduces a new methodology that quantifies the present advancement in the integration of progressive research, and reports its results.

2. Analysis of R&D activities based on patent data

It is common to use patent data for the qualitative and quantitative analyses of R&D in companies due to the fact that they are the collections of inventions in any technological fields under coherent categorization [6]. Particularly, patent data is assumed to be an effective index for measuring the effects of R&D activities in large enterprises [7]. With the help of an input-output table, Gemba and Kodama visualized the technological tendencies of patent applications [8]. They clarified the relations between the content of applications and R&D costs in order to describe the diversification mechanisms of R&D in Japanese corporations. Similarly, Suzuki and Kodama [9] analyzed the relation between the policy structure of R&D and the management strategy of companies on the basis of patent data.

Besides these research that aimed at specific companies' R&D tendencies, another study attempted to explain the trend in wider technological fields and both the advancement and direction of R&D in enterprises. Pilkington and Dyerson [10] targeted application data in the field of electrical vehicles in order to clarify how environmental control measures on exhaust emissions influenced and accelerated the speed at which R&D was conducted. Furthermore, patent data has been used as a data source for the study of knowledge spillover and diffusion ([13], [14], [15], [16]).

Thus, analyzing studies that use patent data makes it possible to measure and explain various aspects and events related to R&D, and mechanisms of spillover in technological industries. This paper stands upon the same position that patent is one of the most effective measurable data representing R&D activities, and utilizes it in the following analysis.

3. Data and logical approach

3.1. Target data

It is our goal to clarify the current situation of the research based on the integration of leading technologies, in order to shed light on the direction, progress and efficiency of research concerning the given technological sector or each applicant. This paper is a preliminary study which introduces a new analytical method to categorize the R&D status based on patent data.

As is well known, there are two types of patent data: one is the Publication of Unexamined Applications, regarding inventions waiting for examination after applications; the other is the Granted Patent Publication, containing data on inventions that on average waited for more than 18 months since application and finished the examination process. Suzuki and Kodama [9] analyzed the relative share of these two types of data and observed a high correlation between them. In this study, since we focus on the leading edge technologies in early R&D stages, the use of newest data is preferable. Therefore, data from the Publication of Unexamined Applications is used, as it contains the most recent invention information. The data of patent applications in Japan is published monthly on a DVD-ROM by the Japan Institute of Invention and Innovation (JIII). We utilized these DVD's as digital data sources. By programming a small Java application, XML data in each DVD is automatically extracted, converted, and inserted to an RDB (PostgreSQL). Primary patent statistics in the following section is obtained from this database.

Concerning the technological field, this research focuses on the fuel cell, because it is considered to be one of the most important developing technologies. Indeed, the importance of this filed is pointed out in two official data publications in Japan: "R&D Focus in Technological Fields" from the New Energy and Industrial Technology Development Organization (NEDO), and "Important Patent" in the "Technical Trend Investigation" edited by the Japan Patent Office. Meanwhile, as regards to practical applications of the fuel cell technology, knowledge intensive research in two specific different research area, i.e., chemistry and engineering, is necessary and making progress, such as that in electrolyte, electrolyte membrane and equipment miniaturization. Therefore, fuel cell technology is an appropriate target for the research on the fusion of cutting-edge technologies. In the following sections, we use the Publication of Unexamined Applications data in this technological field for the years 2004 and 2005.

3.2. Technological classification

This paper focuses on the International Patent Classification (IPC) given to each patent document, and identifies the technological fields of inventions and the types of technological combinations. Used worldwide, IPC is a code that classifies technologies and is given to invention data to identify into what field of technology the data belongs to. In Japan, examiners related to the specific technological field from the Patent Office assign IPC to each application data, thus asserting the reliability of the classified invention.

IPC categorizes technological fields into a five-level hierarchical system (from the broadest to the very specific): "Section", "Class", "Subclass", "Main Group", and "Sub Group". For example, the fuel cell battery field belongs to a main group H01M8, reflecting the above-mentioned hierarchy: "H" identifies the section "Electric", "H01" the class "Electric element", and "H01M" represents the subclass "Process or means for the direct conversion of chemical energy into electrical energy". Finally, the Sub Group is represented by adding a slash symbol (/) and two numerical digits to the numerical digit of the Main Group.

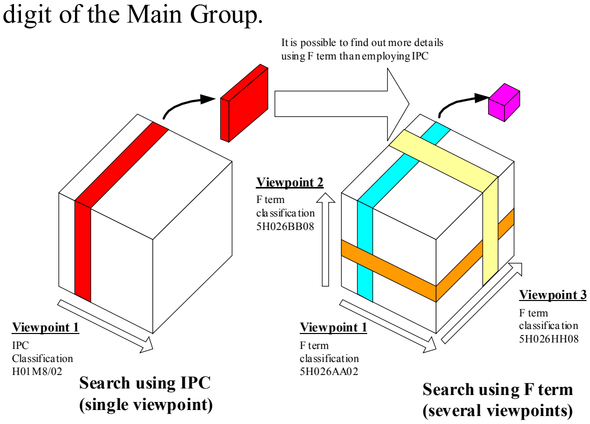

Figure 1. F term classification concept (cited from patent map guidance in Japan industrial property digital library)

In addition to IPC, the File Forming Term (commonly named F term) is given to the Publication of Unexamined Applications in Japan. The F term system, which is unique to Japan, reclassifies the IPC by technological viewpoints, such as the purpose, usage, structure, material, manufacture process and control means, into proper technological fields. Each technological field is expressed by a five-digit alphanumerical code called "theme code". For instance, the theme code "5H026" refers to "fuel cells (main units)", while "5H027" to "fuel cells (systems)". When it comes to F terms, two letters representing the viewpoints and two digits are added.

3.3. Logical approach

3.3.1. Categorization of patents based on IPC. The number of IPC codes given for each patent application document is equal to or greater than one. In other words, it is not uncommon that multiple IPC codes appear in a single patent document. Using this property, we define the types of technological integration. In IPC, two categories exist: the "Main IPC" and the "CO-IPC". The former is allotted for any patent, while the latter is either not granted at all or sometimes given more than one. The main IPC represents the primary technological field of the invention; on the other hand, the CO-IPC stands for other technical characteristics simultaneously contained in the invention. If the invention document (patent) is provided multiple IPC, and if each of the assigned IPC belongs to a different technological field, the case is referred to as "IPC Co-Occurrence" [9]. This concept has been used for studies of the knowledge spillovers between different sectors, and the combination of different core technologies within companies ([11], [12]).

In studying fusion of technologies or the spillover, there exists a different analytical approach based on R&D expenditure (for overheads and staff) and the Main IPC [13]. It is mentioned afterwards that the method based on IPC Co-Occurrence is more appropriate for extracting genuine technological linkages [11].

IPC Co-Occurrence gives a basis for the analysis of technological combination in the sense that it represents the existence of different technological fields in one invention document; however, there are various types of inventions and innovations such as the ones which combine similar but different technologies, and the ones that focus on narrower areas of technological elements and trigger off breakthroughs. Therefore, in order to grasp the various types of innovations, this paper expands the concept of IPC Co-Occurrence.

Patent can be defined into three categories: the first type is for patent data that obtains multiple IPC codes in different technological fields; the second one is for patent having more than one IPC codes in an identical technological field; and the third type is for a patent with a single IPC code. The first category is named Mix Type (integration of different technological fields), the second is the Only Type (integration of technologies in the same field) and the third one is the Mono IPC Type (single technological element).

The Mix type is identical to the concept of IPC Co-Occurrence, while the Only type inventions include several technologies within one same field. The Mono IPC type, unlike other types, refers to "single technological element type or single focus type" inventions, which stand for inventions that concentrate and deepen on a specific technological field.

The categorization defined above is valid not only for patents in Japan but also for those in other countries. For example, the European Patent Office (EPO) grants ECLA (The European Classification) codes, which is an extension system of IPC, to each patent application. Therefore, categorization defined above is considered to be applicable to European patents. In contrast, this categorization may not be applicable to US patents directly, since IPC is not primary classification code. Instead of IPC, USPC (US Patent Classification) system, which is basically independent of IPC, is utilized for US patents. However, in this case, it is possible to re-define three types (Mix, Only and Mono) by using USPC codes in each patent instead of IPC's. In this way, the concept of patent categorization described above is applicable to patent data in any country only if reliable (and multiple) classification codes are given to each patent.

3.3.2. Innovation position. Based on the categorization introduced in previous subsection, characteristics of given patent dataset, for example, patent applications of a specific enterprise, can be investigated numerically. Not only the numbers of the Mix, Only and Mono-type applications but also the ratio of each type gives useful information. Regarding these ratios as coordinates in a three dimensional space, the position of each patent dataset can be defined. Hereafter, let us call the position "innovation position".

To visualize the innovation position, a three dimensional perspective is not necessary since a two dimensional projection gives sufficient information. Indeed, since the sum of the ratios of Mix, Only and Mono types always equals to 100%, if we define a coordinate by the triplet of each ratio as $(x_{MIX}, x_{ONLY}, x_{MONO})$, the innovation positions distribute on a plane surface $x_{MIX} + x_{ONLY} + x_{MONO} = 100$ (%) (figure 2).

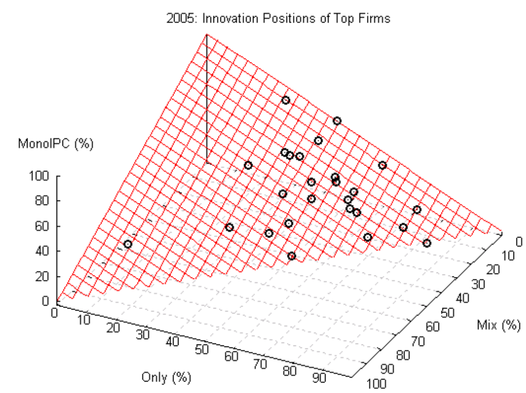

Figure 2. Innovation positions of the top 26 applicant companies in the fuel cell field (2005)

In other words, since a constraint exists, if two out of three numerical ratios are decided, one is uniquely determined. Thus, the two-dimensional projection provides enough information about innovation positions.

In evaluating or confirming differences or varying trends of innovation positions, one can utilize various methods in statistics. For example, statistical significance of the difference between two innovation positions can be confirmed by chi-square test.

Table 1. Number of patent application in Japan by sections in years 2004 and 2005

Section	A	B	C	D	E	F	G	H	
Descrip-tion	Human necessities	Performing operations; transporting	Chemistry; metallurgy	Textiles; paper	Fixed constructions	Mechanical engineering; lighting; heating; weapon; blasting	Physics	Electricity	Total
2004	39,530	64,362	34,196	4,152	14,524	32,089	91,822	83,784	364,459
2005	38,773	62,701	31,674	3,905	13,551	31,927	89,343	82,995	354,869

4. Analysis and results

4.1. Overview of patent applications

Regarding the data on the number of patent applications, the totals for the years 2004 and 2005 were 364,259 and 354,869 respectively (Table 1). The target area of this paper is "Fuel Cells; Manufacture thereof", classified under the IPC "Main Group" category with the code H01M8. In this category, there were 2,164 applications in 2004 and 2,874 in 2005. They accounted for 2.6% and 3.5% of total applications in Section H, respectively, and for 0.6% and 0.8% of overall patent applications.

Based on the relation between the Main IPC and CO-IPC, this paper examines patent application data grouped under H01M8. When the classification introduced in the previous section is applied on integrated technologies, the followings are the three categories related to H01M8 inventions: (1) "Mix type" is the application data given one Main IPC code and one or more CO-IPC code in the technological field different from H01M8; (2) "Only type" provides data granted all CO-IPC belonging to H01M8; (3) "Mono IPC type" includes data with a Main IPC without CO-IPC.

4.2. Current status of technological development in the fuel cell field

As mentioned above, while the number of applications is decreasing in general, the number of patent applications in the fuel cell field (H01M8) is increasing. In 2004, there were 280 applicants for 2,188 applications, and one year later, those figures rose to 327 for 3,206 requests. Comparing these two years, the increase in applicant numbers was 17%, while the growth in applications was 47%, the reason lying in the rise of applications by large corporations. Indeed, the first 29 companies for 2004, ranked by the number of applications according to applicants, accounted for 1,527 applications or 69.8% of the total. However, in 2005, the top 26 companies represented 2,232 applications (or 69.9%). For those enterprises, the average number of applications per company was 53 in 2004, while 86 one year later, representing a 63% growth. This explains the significant increase in application numbers.

As for the distribution according to application document types, there were several Only (same field integrated technologies), followed by Mono types (innovations from a single technological element), and the smallest amount came from the Mix type (different field integrated technologies) in 2005 (Table 2.). Regarding the trend, the ratio of types linked to integrated technologies is decreasing (-4% for Mix and -5% for Only), while the Mono ratio is going up (+9%).

This trend indicates that inventions of the single technological element type are growing when compared to the ones from the integrated technology type; however, to analyze this point, it is necessary from now on to obtain more yearly data.

Table 2. Applications in the fuel cell (H01M8)

Type	2004 (280 applicants)		2005 (327 applicants)	
	Number of applications	Ratio	Number of applications	Ratio
Mix	614	28%	761	24%
Only	1,035	47%	1,360	42%
Mono	539	25%	1,085	34%
Total	2,188	100%	3,206	100%

As mentioned above, only 11% of all applicant enterprises accounted for 70% of all applications for the year 2004 and one year later, 8.6% of companies represented the same ratio; a breakdown by industrial sectors of the main companies is illustrated in Table 3. (the industrial type classification is based on the Securities Identification Code classification).

For the years 2004 and 2005, the industry sectors with substantial application numbers are the transportation equipment and electrical equipment industries, and their combined applications accounted for 60% of total applications. In particular, the transportation equipment industry equaled to 40% of total applications in 2004 and 44% in 2005, representing the largest industrial sector. Additionally, the number of applications by company in this industry was 124 in 2004 and 176 in 2005, while the average in other industries was less than 50 applications.

Table 4. shows the application numbers sorted according to classification type, for the two industries that represent the highest figures in terms of applications in the H01M8 field. In Table 2., representing the total number of applications in the fuel cell field, the category Only type, which refers to the same field

Table 3. Breakdown by industry type of applications in H01M8 for the top ranked companies

2004				2005			
Industrial type	Number of enterprises	Number of applications	Ratio	Industrial type	Number of enterprises	Number of applications	Ratio
Transportation equipment	7	871	40%	Transportation equipment	8	1,404	44%
Electric equipment	14	451	21%	Electric equipment	11	602	19%
Electricity, gas	3	69	3%	Electricity, gas	2	73	2%
Machinery	2	60	3%	Machinery	2	55	2%
Non-ferrous metal	1	34	2%	Non-ferrous metal	1	47	1%
Chemistry	1	21	1%	Chemistry	1	21	1%
Glass, soil and stone goods	1	21	1%	Other goods	1	30	1%
Top-ranked applicant total	29	1,527	70%	Top-ranked applicant total	26	2,232	70%
Total for 2004	280	2,188	100%	Total for 2005	327	3,206	100%

Table 4. Application number distribution in the field H01M8 for the two industrial sectors occupying the top ranks in terms of applications

Transportation equipment					Electric equipment				
Type	2004		2005		Type	2004		2005	
	Freq.	Ratio	Freq.	Ratio		Freq.	Ratio	Freq,	Ratio
Mix	185	21%	246	18%	Mix	90	20%	124	21%
Only	404	46%	522	37%	Only	261	58%	326	54%
Mono	282	32%	636	45%	Mono	100	22%	152	25%
Total	871	100%	1,404	100%	Total	451	100%	602	100%

integrated technology type, contained the highest frequency of applications for 2004 and 2005; however, in the transportation equipment industry in 2005, Mono occupied the largest share. This sector is considered to be undergoing structural change, as shown by the facts that Only and Mix types decreased by 8% and 3% respectively between the two years, while Mono went up by 11%. On the opposite, no such drastic change has occurred in the electric equipment industry. The main feature of this sector is the large number of Only type, which accounts for more than 50% of total applications in both 2004 and 2005. By utilizing chi-square test, the descriptions above about varying technological trends in these two sectors are supported. Indeed, concerning a null hypothesis that "innovation position did not change in these two years", (i) it is rejected for the transportation equipment industry ($P < 0.01$) while (ii) not rejected for the electric equipment industry ($P > 0.05$).

The main reason behind this distribution amongst types can be explained by examining the features of application characteristics, such as the use of fuel cells in transportation and electrical equipment sectors. As for transportation equipment, strong expectations have been put on the fuel cell as an alternative source of energy for cars. On the other hand, an important potential rests in the use of electric equipment, such as household cogeneration energy, personal computers and mobile phones, which occupy a significant market share. Regarding the size of equipment for electrical generation, this characteristic is not essential for automobiles and household cogeneration; nevertheless, miniaturization is of significant importance for portable AV equipment. In transportation equipment, a prototype vehicle has been developed and we can affirm that the use of fuel cell in that industry is at its final stage of research technology development. On the other hand, miniaturization remains the main technological obstacle in portable AV equipment; consequently, R&D in the fuel cell has not yet reached its convergence phase. Thus, a rise in Mono type applications implies that research and development in a specific field has arrived at its final stage. In this way, by applying the categorization of patent data as introduced in this paper, it is possible to grasp quantitatively the current status of research and development.

4.3. Innovation position of firms

In this way, it is possible to classify the tendency of patent applications from a new point of view. This categorization method is also effective to analyze application tendencies of individual and company applicants. Indeed, the share of patent applications for the Mix, Only and Mono types can be calculated for each company. Regarding these ratios as coordinates in a three dimensional space, innovation positions of firms are introduced.

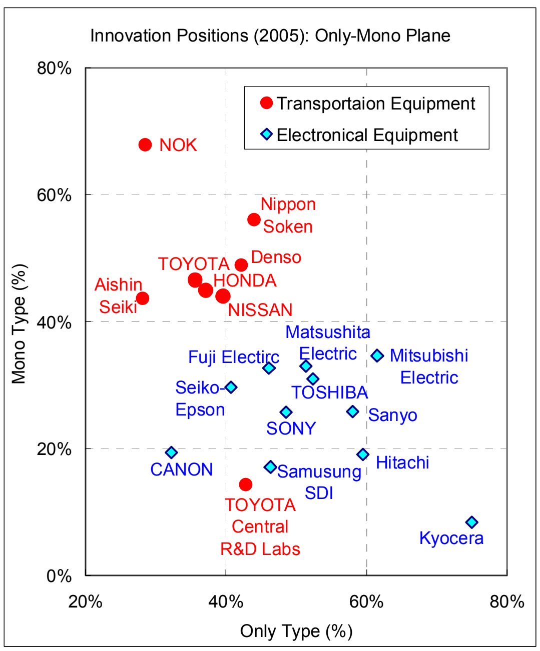

Figure 3. Differences in innovation positions of the two main industrial sectors in 2005

Figure 3. shows the projection onto Only-Mono plane of the innovation position of each company in the two most prominent industrial sectors, i.e., "transportation equipment" and "electric equipment". It is clearly shown in Figure 3 that the distributions of two sectors are clearly separated.

Regarding the distribution of applicants, three companies, Toyota Motor Company, Honda Motor Company and Nissan Motor Company, occupied the top ranks during the two years. The number of applications for these three companies accounts for 35% of total applications, and though the ranking amongst them varies, they steadily dominate the fuel cell field.

For those companies, the transitions in innovation positions and application numbers by type are presented in Figure 4. Both charts indicate the transition of the Only/Mono IPC on a two dimensional surface. Figure 4. (a) reveals that Toyota obtained the largest increase in application numbers, followed by Nissan, while Honda experienced a small decrease. Regarding the number of applications, the gap between Honda and other firms has enlarged through the two years, and Figure 4. (b) converts those figures into innovation positions. As the innovation position is an indicator of the applications' characteristics made by companies, we can observe that the companies' positions are getting closer to each other over the two years. According to the chi-square test, a null hypothesis that "these top three companies stay at an identical innovation position" is (i) rejected in 2004 ($P > 0.05$) while (ii) not rejected in 2005 ($P < 0.05$).

On the other hand, as indicated in Figure 3., transportation equipment manufacturers occupy more diversified positions than the three companies above, the reason being that parts manufacturers conduct their research on specific domains of transport equipment where they have an advantage. Noteworthy are the differences in innovation positions between "Toyota Central Research and Development Laboratories" and "Nippon Soken Inc." in 2005. Both organizations are R&D specialists affiliated to Toyota, and the breakdown in application data for "Toyota Central R&D Lab." is 43% for Mix, 43% for Only and 14% for Mono, while that for "Nippon Soken" is Mix 0%, Only 45% and Mono 55%. The difference in the Mix ratio is remarkable, which explains the dissimilarity in innovation positions. In other words, research at "Toyota Central R&D Lab." utilizes a wide array of technologies, while "Nippon Soken" specializes in the development of a limited technological field. This demonstrates how effective innovation position is as one of the quantitative indicators for assessing the characteristics of companies' core competences.

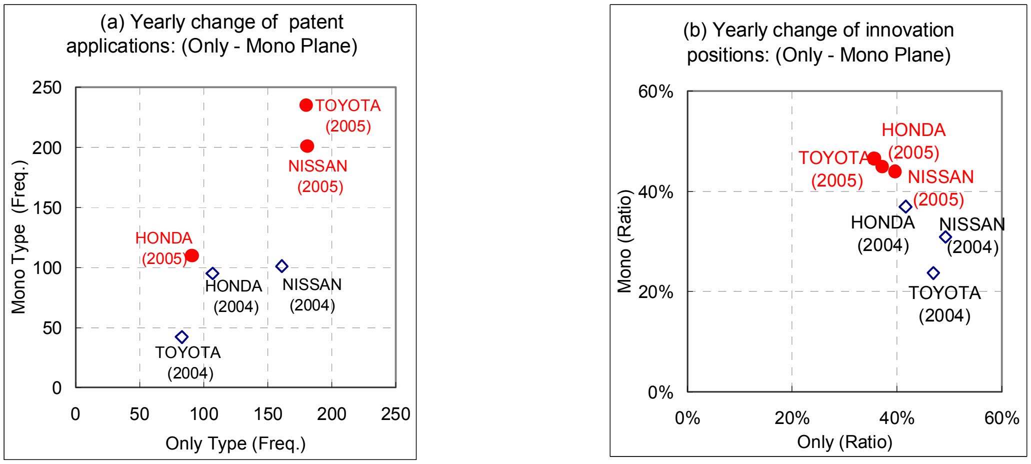

Figure 4. Yearly change of patent applications and innovation positions of the top three companies

Table 5. Applications in the lower-ranked group (less than three applications a year)

Type	2004 (193 applicants)		2005 (216 applicants)	
	Total Applications	Ratio	Total Applications	Ratio
Mix	142	49%	111	36%
Only	95	33%	107	35%
Mono	52	18%	92	30%
Total	289	100%	310	100%

Besides the top three companies, the results for the ones applying in smaller numbers are presented using the same analytical method in Table 5. It shows the categorization of applications by the lower-ranked applicants who applies less than three patents a year. The number of applicants belonging to this group was 193 in 2004 (accounting for 69% of all applications) and 216 for 2005 (66%). This group contains not only companies but also individual applicants. By definition, derivation of innovation position for each applicant in this group is not effective since the number of applications is too small. Therefore, the ratio of each type is calculated for the aggregated data of all the constituents in the group. It is worth mentioning that the Mix type is dominant in Table 6. In 2004, half of total applications in this group were Mix, differing from the distribution of the top three companies. This tendency is unique to this group, the reason possibly being that its constituents are presently in the early development phase. On the contrary, the top ranked motor companies are in their final stage towards the goal of bringing the experimental cars to the markets by 2010. In such a stage, it is reasonable that Mono-type applications become dominant because each technological element for production has to be ameliorated. On the other hand, it is assumed that lower-ranked applicants innovate without restriction. In 2005, while the share in Mix decreased and reached almost the same level as Only, it still remained the highest ratio amongst the three types. As for the trend between the two years, 1- Mix type decreased, 2- Only type increased slightly, and 3- Mono type grew significantly. Regarding the last point, both the top three companies and the rest of applicants show a similar tendency.

4.4. In-depth analysis of the technological field using F-terms

Before the conclusion of this paper, the information of F term is added in order to deepen the previous analysis based on IPC. Different from the IPC codes, the F term is systemized from technological viewpoints. Therefore, F term is useful to extract characteristics and differences amongst companies who have similar innovation positions.

It is shown in Table 6. the frequencies of F terms in the applications by the top three companies (Toyota, Nissan and Honda). There are significant differences in the numbers of variations of theme codes for each document type. There are more than 60 varieties of theme codes in the Mix type, while a fewer number appeared in Only and Mono types. Besides, the differences between the three types can be clearly seen in the contents of theme codes. For example, as for Mono and Only-types in the applications by Toyota, the total amount of the theme codes “5H026” (Fuel Cells (Main Units)) and “5H027” (Fuel Cells (Systems)) represents approximately 98% to 100% of all the theme codes appeared in each type, while they occupy less than 40% in Mix type. This tendency can also be witnessed in Nissan and Honda; however, it has been revealed that each company has unique theme codes in the Mix type document.

Table 6. Theme codes of F terms in applications by the top three companies (Toyota, Nissan, Honda)

Type	2004		2005	
	Theme code	Freq.	Theme code	Freq.
Mix	62 kinds	3,006	75 kinds	3,200
Only	5 kinds	2,111	5 kinds	2,954
Mono	4 kinds	1,315	6 kinds	3,029
Total	71 kinds	6,432	86 kinds	9,183

The distribution of theme codes in Mix by companies is shown in Table 7. For 2004 and 2005, the top ten theme codes and their frequencies are displayed for the three companies. In 2004, the theme code with the highest numbers was “5H115” (Electrical Impulsion, Braking of Vehicle); however, in 2005, each company showed a different result. Toyota’s first theme code was “5H018” (Non-Wastage Electrode), while Nissan was “5H027” (Fuel Cells (Systems)) and Honda “5H026” (Fuel Cells (Main Units)). Regarding the two last companies, the theme codes frequently appearing in Only and Mono are the same, however, looking thoroughly at Table 7. reveals that the application trend for each company is reflected in other theme codes. For example, Nissan accounted 114 out of 131 applications (or 87%) in “4G069” (Catalyst) for the two years, while Honda recorded 44 applications from a total of 53 (83%) in the theme code “3H106” (Magnetic Drive Valve). These observations illustrate the differences in technological development emphasis for each company.

In this way, by adding the information from the F term to the companies who have similar innovation positions, a multilayer analysis can be carried out in order to investigate the R&D strategies in each company.

5. Conclusion

In order to analyze researches based on the integration of leading edge technologies, this paper introduced three types of patent data categorization, namely the Mix, Only and Mono type, respectively, by expanding the concept of IPC Co-Occurrence. Additionally, the concept of innovation position is introduced as a mean to investigate status and trends of R&D in the field of fuel cells for the years 2004 and 2005.

In this technological field, the two dominant industries are the “transportation equipment” and “electric equipment”; by utilizing chi-square test, it is shown that the former industry changed its innovation position while the latter did not in these two years. It is also shown that innovation positions amongst enterprises differed clearly according to industries, which is assumed to be based on the differences in application objects and also in development phases between industrial sectors. Simultaneously, this paper showed that the disparities between the characteristics of the companies’ core competences are visualized by innovation positions: technical uniqueness of the enterprise is directly reflected to the innovation position. Moreover, dissimilarities exist between “dominant companies” and the “lower-ranked applicant group” with regards to innovation positions. It has been shown that the latter group, which possesses less additional constraints on inventions, holds a higher ratio for the Mix type compared to the top ranked applicants. Lastly, by adding the information of F terms to IPC codes, the top three companies in the transportation equipment industry are investigated in detail. It is shown that development trends and also the focuses in technological elements of each company are clearly illustrated by utilizing both F terms and IPC codes.

Though this novel approach is still in preliminary phase, both the categorization based on IPC and the concept of innovation position are considered to be effective analytical tools for quantitative R&D studies, since they provide both a united and quantitative new standpoint that is especially efficient for the analysis of integrated technologies. The authors are going to continue the investigation, increasing data sets, and expanding the target industrial arena, in order to clarify the progress and efficiency of research based on integrated advanced technologies.

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Table 7. Distribution by company of theme code appearance frequency for Mix type documents

Frequency of F terms in MIX type documents by theme code		2004				2005				TOTAL
		Toyota	**Nissan**	**Honda**	Total	**Toyota**	**Nissan**	**Honda**	Total	(2 Years)
5H115	Control of electrically-propelled vehicles	**407**	**309**	**253**	**969**	219	210	59	488	1,457
5H027	Fuel cells (systems)	186	266	166	618	275	**273**	99	**647**	1,265
5H026	Fuel cells (main units)	114	94	169	377	257	148	**160**	565	942
5H018	Inert electrodes	63	37	144	244	**277**	81	68	426	670
4G140	Hydrogen, water and hydrids	56	59	45	160	66	90	47	203	363
4G069	Catalysts	0	78	9	87	8	36	0	44	131
4D006	Separation using semi-permeable membranes	24	8	0	32	8	46	9	63	95
3J040	Gasket seals	0	0	0	0	21	0	41	62	62
3G091	Exhaust gas after treatment	17	0	0	17	36	0	0	36	53
3H106	Magnetically actuated valves	0	0	26	26	9	0	18	27	53
Sub-total of top 10 codes		867	851	812	2,530	1,176	884	501	2,561	5,091
Total		1,050	1,055	901	3,006	1,442	1,130	628	3,200	6,206