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PUBLICATION TRENDS IN TECHNOLOGY ROADMAPPING

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ABSTRACT

This study aims to identify the trends in technology roadmapping based on the bibliometric analysis of more than two decades of references. The analysis focused on the types of publications (e.g., journal and conference), contexts of publications (e.g., international and national), and key themes (e.g., NPD and R&D) extracted into six groups of five-year interval time-periods each. The analysis on 699 references has revealed the interest on technology roadmapping was only started to increase since 1996-2000 time-periods with 38 publications, and have reached the highest peak with 305 publications in 2006-2010 time-periods. In details, both journal and conference were almost equal in numbers of publications, in which Technological Forecasting and Social Change was found to be the top journal, while IEEE is the top organizer with PICMET as the leading conference. Despite of most of the articles were written with generic titles, 12 of them have been identified written on international context (e.g., Asia Pacific and Europe), 78 on national context (e.g., China and Japan), and 14 on organizational context (e.g., Siemens and Motorola). In addition, the analysis has also found 17 key themes of studies led by ICT, innovation, and energy. Although the analysis was based on a single source of database with some limitations, future studies should pay more attention on the importance of technology roadmapping on the international context, emphasis on developing countries on the national context, focus on SME on the organizational context, and explore the applications of technology roadmapping on the non-technological themes.

Keywords: *Article titles, bibliometric analysis, references, technology management*

BACKGROUND

Technology roadmapping is “a technique to capture diverse information in technology evolution and new product development” (Petrick & Echols, 2004, p.89). It is part of technology planning that deal with increasing competitive environment (Garcia & Bray, 1997). Technology roadmapping is crucial for creating alignment between technology

and organizational goals (Phaal, Farrukh, & Probert, 2005). One of the main applications is to support strategic planning in relations to technology, product, and market (Phaal, Farrukh, & Probert, 2004). It can also be applied for other purposes, such as service planning, capability planning, long-range planning, knowledge asset planning, program planning, process planning, and integration planning (Phaal, Farrukh, & Probert, 2001). The initial works on technology roadmapping was appeared for the first time in the late 1970's (Phaal, Farrukh, & Probert, 2005). With over two decades of literatures, the ground works on technology roadmapping should have been well established. As a result, this study aims to identify the trends in technology roadmapping based on the bibliometric analysis of references.

STUDY METHODOLOGY

A bibliometric analysis that was based solely on the references and article titles was applied due to proven applications in previous studies. One example of the studies has categorized the article titles into methods-describing titles and results-describing titles (Paiva, Lima, & Paiva, 2012). Meanwhile, another study has classed the types of article titles into descriptive, declarative, and question (Jamali & Nikzad, 2011). Prior to that, a study has classified the article titles according to the methods, dataset, results, conclusions, and topics (Goodman, Thacker, & Siegel, 2001). For the purpose of this study, the analyses are focused on the types of publications, contexts of publications, and key themes, where the types of publications are grouped into books (including chapter in books, and reports), journals, proceedings (including conferences, seminars, symposiums, summits, conventions, etc.), and theses and dissertations (Master and PhD levels). Meanwhile, the contexts of publications are grouped into international (e.g., regional, treaty, and bloc), national (including state in a country, government institutions, authorities, and agencies), and organizational context (for private and profits firms). In a similar fashion, the key themes are grouped based on the emphasis, focus, context, or topic highlighted in the article titles. The data for these classifications were extracted into six groups, each with a five-year interval time-periods from pre-1991 to 2011-2015 group. The database is taken from a list of more than 700 references in Phaal (2015). Prior to analysis, the quality of all 739 references were inspected, and have found 23 of them written in non-English, 12 being listed twice, four without year, and one without title, all of which were omitted from the database. The remaining 699 references consisted of 262 articles with "technology roadmapping" wording in the titles (including technology roadmap, technology road mapping, technological road map, technological road-mapping, etc.), 336 articles with only "roadmapping" wording (including roadmap, road map, road-map, road-mapping, etc.), and 101 articles with none of the above wordings. Nevertheless, depending on the types of information, not all references can be recorded in every classification. This analysis was performed according to the following methods: (1) mapping the field through a scoping review, (2) comprehensive search, (3) quality assessment, (4) data extraction, (5) synthesis, and (6) write up (Jesson, Matheson, & Lacey, 2011).

DATA ANALYSES AND TRENDS

The results of data analyses on the trends of technology roadmapping on the types of publications, contexts of studies, and the key themes are discussed as follows:

Trends in Publications

Table 1 is suggesting four main types of publications for technology roadmapping. Out of 699 studies, 95 of them were published in books and reports, 295 in journals, and 280 in proceedings and conferences. In addition, this discipline of study has so far produced 29 scholars as suggested by the numbers of theses and dissertations, which means technology roadmapping has been recognized as one of important academic subjects by the universities. Meanwhile, regardless of the type of publications, a total of 58 case studies have been published begun with just one study in 1996-2000 to 20 studies in 2011-2015 time-periods. This shows that case study has started to get attention as an alternative method to study technology roadmapping.

Table 1
List of publications

Classifications \ Years		Pre-1991	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	Total
Total Numbers of Publications		2	5	38	168	305	181	699
Types of Publications	Books/Reports			10	23	41	21	95
	Journals	2	3	9	64	133	84	295
	Proceedings/Conferences		2	17	74	116	71	280
	Theses/Dissertations			2	7	15	5	29
	Case Studies (from various publications above)			*1*	*10*	*27*	*20*	*58*

Further descriptive analysis in Figure 1 has found all types of publications have reached the highest peak in 2006-2010 time-periods. Although the numbers of publications in journals and proceedings have not much different over time, journals have replaced proceedings to be the most preferred type of publications after 2001-2005 time-periods. It can be concluded that knowledge on technology roadmapping was initially developed, discussed, and shared mainly in conferences (especially between 1991 and 2005) before started to gain popularity among wider group of scholars. This suggests that conferences

are the effective platform to promote technology roadmapping. Similarly, even though studies on technology roadmapping can be tracked back way before 1991, it was only becoming obvious in the radar after 1995. It is worth noting that all types of publications were suddenly dropped in 2011-2015 time-periods. This was believed to happen due to not all publications in the most recent time-period have been made available and recorded. Despite of that, the trend of all types of publications was relatively unchanged. Another possible reason for the drop in numbers of publications could be caused by declining interest on technology roadmapping in the recent time-periods.

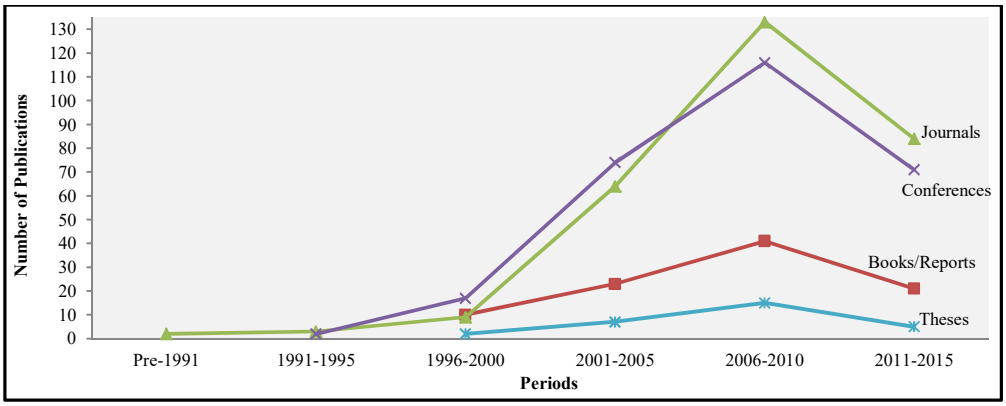

Figure 1
Trend in publications

Figure 2 shows the result of Google Trends search on "technology roadmapping" and "technology roadmap" keywords from January 2004 to December 2015 (maximum range allowed by Google). It was obvious from the graph that the trends of search on both keywords have been consistently decreasing. Therefore, something needs to be done in order to understand the reasons behind dropping trends of search in technology roadmapping, which could help on improving the knowledge on this discipline of study.

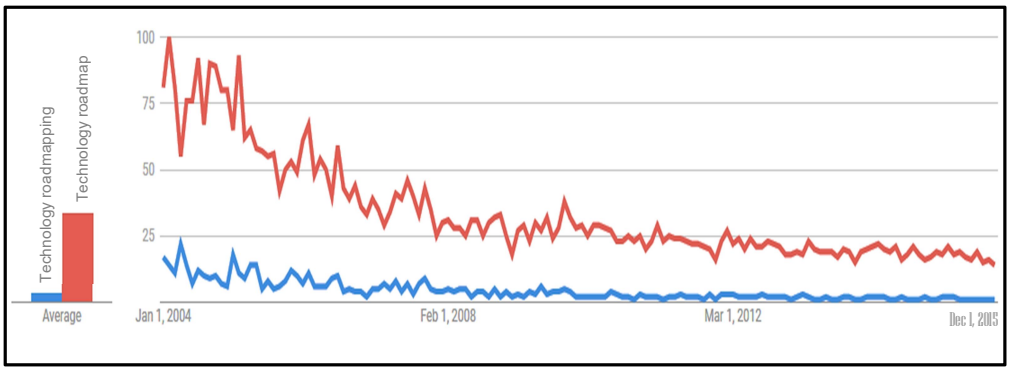

Figure 2
Google Trends search on "technology roadmapping and roadmap" keywords

Trends of Publication in Journals

A total of 15 main peer-reviewed and indexed journals are recorded in Table 2. With 48 articles, Technological Forecasting and Social Change is the most preferred journal for technology roadmapping, followed by Research-Technology Journal (19 articles), and International Journal of Technology Intelligence and Planning (14 articles). In contrast, the other 12 journals only published 49 articles in total. Meanwhile, 165 articles were published in various journals under "others" category.

Table 2
List of top journals

Years / Classifications	Pre-1991	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	Total
			1		1	1	3
					3	2	5
Engineering Management Journal							
					1	2	3
Energy Policy							
International Journal of Innovation Management				4	9	1	14
International Journal of Technology Intelligence and Planning							
			1	2	1		4
International Journal of Technology Management				1		2	3
Journal of Cleaner Production							
Journal of Engineering and Technology Management						3	3
				1	2	1	4
R&D Management							
				1	1	2	4
Research Policy							
			1	10	6	2	19
Research-Technology Management							
			1	2			3
Science							
				13	19	16	48
Technological Forecasting and Social Change							
Technology Analysis and Strategic Management					2	7	9
Technology in Society					2	1	3
Technovation					3	2	5
Others	2	3	5	30	83	42	165

Although Technological Forecasting and Social Change, Research-Technology Journal, and International Journal of Technology Intelligence and Planning are the top three journals for technology roadmapping, the trend was appeared to have slightly changed in the recent years. As shown in Figure 3, the total numbers of publications in both Research-Technology Journal, and International Journal of Technology Intelligence and Planning have been declined in the recent years. In contrast, Technology Forecasting and Social Change has continued to be on the top of the list. At a meantime, Technology Analysis and Strategic Management has emerged to be the second most popular journal in the recent time-period. In summary, various peer-reviewed and indexed journals have started to publish articles on technology roadmapping since 2001. However, most of these journals have published very few articles each and have all concentrated about the same spot on the graph in the latest time-periods (2011-2015).

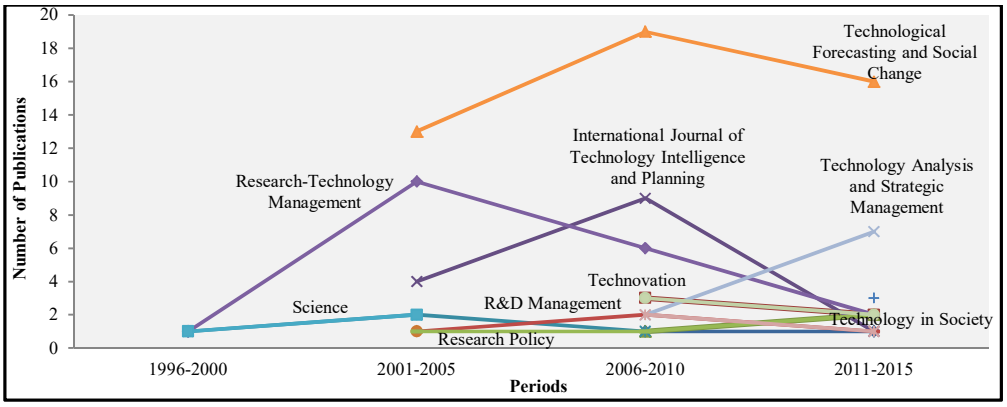

Figure 3
Trend of publication in journals

Trends of Publication in Conferences (Proceedings)

Table 3 shows the main conferences on technology roadmapping published since 1991. With 72 articles, it was very clear that the Portland International Conference on Management of Engineering and Technology (PICMET) is the top conference. Other important conferences are the International Conference on Management of Technology (14 articles), IEEE International Engineering Management Conference (11 articles), and Waste Management Conference (10 articles). Meanwhile, half of the top conferences have been organized by IEEE, which make IEEE as the most active and important organizer.

Table 3
List of top conferences

Years / Classifications	Pre-1991	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	Total
				5			5
EU-US Seminar: New Technology Foresight, Forecasting & Assessment Methods					3	1	4
IEEE International Conference on Industrial Engineering and Engineering Management				2	7		9
IEEE International Conference on Management of Innovation and Technology				1	2	1	4
IEEE International Conference on Requirements Engineering			2	8	1		11
IEEE International Engineering Management Conference			1	1	9	3	14
International Conference on Management of Technology							
Portland International Conference on Management of Engineering and Technology		1	1	17	33	20	72
R&D Management Conference				2	1	2	5
Waste Management Conference				10			10
Others (with IEEE)			1	5	8	14	28
Others		1	12	23	52	30	118

Figure 4 shows the top nine conferences for technology roadmapping. The figure is clearly indicated that PICMET that was very much at the same level with the other conferences in 1996-2000 time-periods has become the best conference for technology roadmapping and maintained the top place until now. The same trend was also observed for the International Conference on Management of Technology that maintained the second place in the recent years, but with much smaller numbers of articles. Meanwhile, with the last conference taken place in 2006-2010 time-periods, the IEEE International Engineering Management Conference has loss the third place to the R&D Management Conference in the recent years.

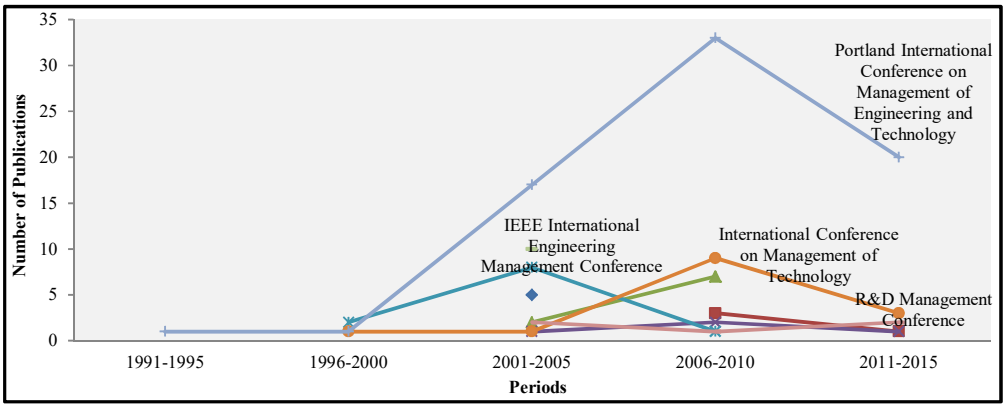

Figure 4
Trend of publication in conferences (proceedings)

Trends on International Context

All studies on the regional level, treaty, or economic bloc are classified under the international context. As shown in Table 4, three studies each were focused on Asia Pacific and Europe, two studies on Pacific Northwest, and one study each on EU-China, Latin America, Nordic, and North America. With the first study appeared in 1996-2000 time-periods, the figures suggest very few studies have been done on international context.

Table 4
List of international studies

Classifications \ Years		Pre-1991	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	Total
International Context *(e.g., regional, treaty, bloc, etc.)*	Asia/Asia Pacific				1	2		3
	Europe				1	2		3
	EU-China					1		1
	Latin America			1				1
	Nordic				1			1
	North America				1			1
	Pacific Northwest					1	1	2

A detail inspection on Figure 5 has found 10 of the studies were published in 2001-2005 and 2006-2010 time-periods. In contrast, there was only one study published, each before and after those time-periods. Meanwhile, no study has attempted to look into the Africa

context. This result could be implying that organizing a study at the international context is a lot more challenging than the other contexts. In overall, it can be concluded that most studies at this level continue to focus on the Asia Pacific, Europe, and Pacific Northwest.

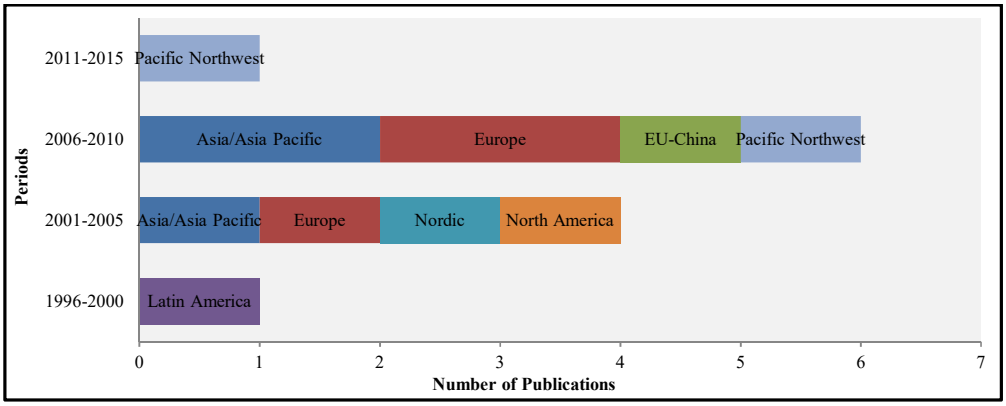

Figure 5
Trend on international studies

Trends on National Context

This context included studies on the states, districts, and governmental agencies, institutions, and bodies at the national level. The attention at this level was only started to increase from 2001-2005 time-periods onwards with 18 studies in 10 countries, followed by 35 studies in 14 countries (2006-2010), and 23 studies also in 14 countries. In details, most studies were focused on China (11 studies) and Japan (10 studies), followed by the US (8 studies), and UK and Korea (7 studies each). Further inspection on the data has identified 51 studies performed in 10 developed countries, and 27 studies in eight developing countries. Therefore, the focus at this level is still inclined towards developed countries. See Table 5 for details.

Table 5
List of national studies

Classifications \ Years		Pre-1991	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	Total
National Context *(e.g., country, state in country, government institutions, authorities, agencies, etc.)*	Australia					2	1	3
	Brazil						2	2
	Canada				1	3		4
	China					5	6	11
	Finland				1	2	1	4
	Hungary					1	1	2
	India					1		1
	Iran					2		2
	Japan				2	7	1	10
	Kenya						1	1
	Korea				3	2	2	7
	Netherlands				1	1	1	3
	Singapore				2		1	3
	South Africa					3	1	4
	Taiwan				1		1	2
	Thailand				1	3		4
	UK			1	2	2	2	7
	USA		1		4	1	2	8

As shown in Figure 6, studies at the national level have been focused on the western countries (i.e., US and UK) before shifted to Asia (i.e., China and Japan) from 2006 onwards. In fact, the studies were led by Japan in 2006-2010 time-periods, while China has taken the lead in 2011-2015 time-periods. Nevertheless, studies on the USA and UK remain relevant.

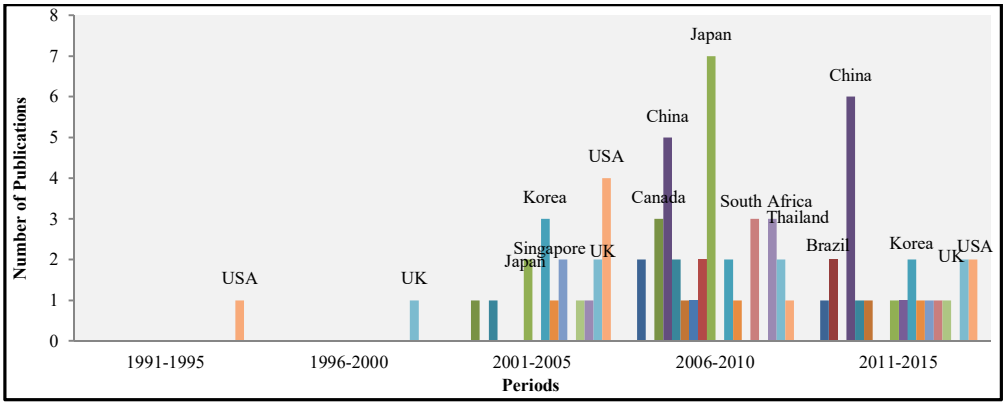

Figure 6
Trend on national studies

Trends on Organizational Context

All firms listed in Table 6 are either private or profit-oriented organizations. Among of these firms, four are the USA origins, namely Cisco (with 1 study), Ford (1 study), Microsoft (1 study), and Motorola (3 studies). Accordingly, Shimano (1 study) and Sony (1 study) are the Japanese origins, while the other two are the European origins with Rolls-Royce (2 studies) in the UK and Siemens (4 studies) in Germany. Although the low numbers of studies may not necessarily means lacking of emphasis at organizational level, more studies should have been done and reported to enhance our understanding on technology roadmapping at this level.

Table 6
List of organizational studies

Classifications \ Years		Pre-1991	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	Total
	Cisco					1		1
	Ford						1	1
Organizational	Microsoft				1			1
Context	Motorola	1			2			3
(e.g., business, private, profit	Rolls-Royce					2		2
firms, etc.)	Shimano						1	1
	Siemens			1		3		4
	Sony					1		1

The following bar chart (see Figure 7) has graphically shown very few scholars have discussed and reported their studies on the specific organizations since pre-1991. In addition, these organizations have at least two similarities – they were multi-national corporations (big companies), and founded in developed countries. As for this reason, there is so far no study has been done especially on the SMEs and in developing countries. Furthermore, study focusing on the non-technological or services organizations should also be explored.

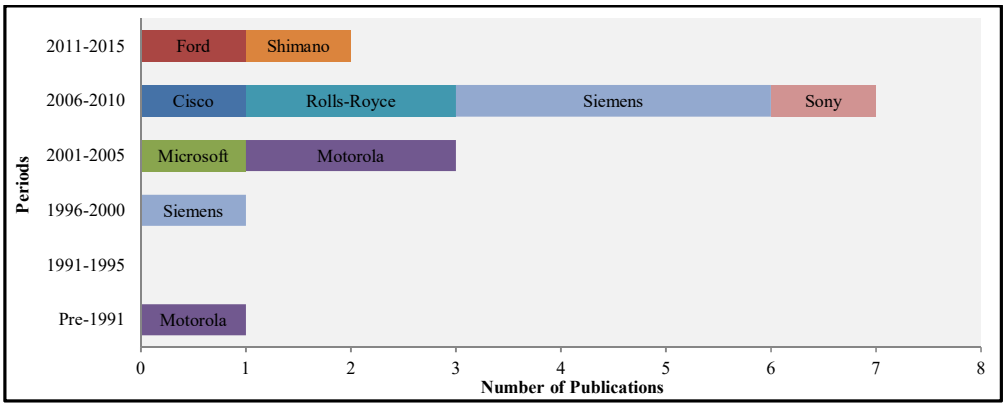

Figure 7
Trend on organizational studies

Trends in Key Themes

As shown in Table 7, ICT (with 70 studies), innovation (55 studies), energy (48 studies), and sustainability (40 studies) are the top key themes, all related to technology disciplines. In contrast, there were five key themes with 10 and below publications, namely, semiconductor (10 studies), SMEs (10 studies), social (10 studies), risk (8 studies), consumer (4 studies), and financial (2 studies). Except for semiconductor, they are all non-technology disciplines. Nevertheless, these results are also implying that technology roadmapping is also relevant to non-technological related themes.

Table 7
List of study themes

Classifications \ Years		Pre-1991	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	Total
Key Themes *(e.g., emphases, focuses, contexts, topics, etc.)*	Consumer/Customer			1	1		2	4
	Energy/Power			2	8	22	16	48
	Financial					1	1	2
	ICT/Computer/Comm.		1		8	40	21	70
	Innovation			1	11	27	16	55
	Knowledge/Learning			3	8	15	7	33
	Manufacturing				2	7	3	12
	Nanotechnology				3	6	3	12
	Policy/Legal		2	2	6	4	5	19
	Product/NPD			1	10	22	5	38
	R&D			1	4	10	5	20
	Risk/Security				1	4	3	8
	Semiconductor		1	2	4		3	10
	Service				1	14	8	23
	SMEs				4	3	3	10
	Social/Community				2	7	1	10
	Sustainable/Green/Envir.			2	8	21	9	40

Based on the graph in Figure 8, although studies have been started early, the emphasis on key themes was only begun in 1996-2000 time-periods, which have reached the highest numbers of studies a decade later in 2006-2010 time-periods. The graph also shows the trend is still emphasized on ICT, innovation, energy, and sustainability since initiation in 1996. At a meantime, semiconductor and nanotechnology have received less emphasis compared to the other technological related themes. Nevertheless, the non-technological related themes, such as knowledge, social, and finance are also growing between 2006 and 2010, and should be maintained in future studies to enhance our knowledge on technology roadmapping.

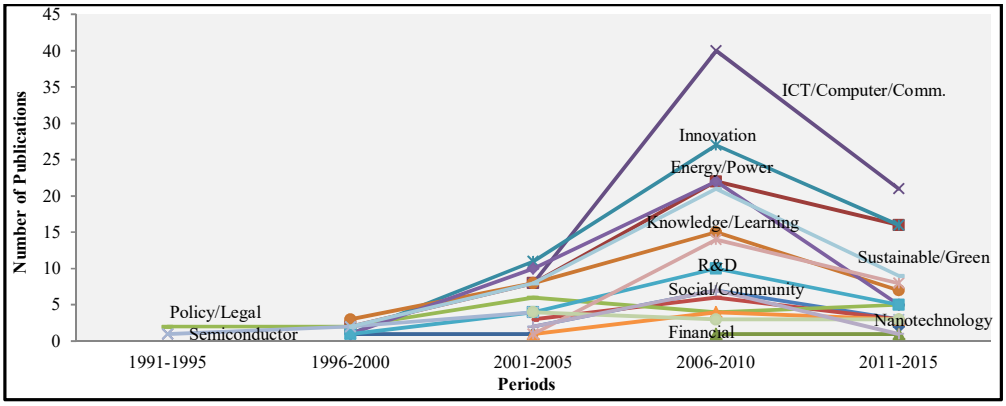

Figure 8
Trend in study themes

DISCUSSIONS

In general, the numbers of publications on technology roadmapping is on the growing side. In fact, the publications have been increased from just two studies reported in pre-1991 time-periods to five studies in 1991-1995, followed by 38 studies in 1996-2000, jumped to 168 studies in 2001-2005, and 305 studies in 2006-2010 time-periods. Although the numbers of publications were declined to just 181 in 2011-2015 time-periods, this could be happen due to not all studies in the recent years have made their ways into the lists. Nonetheless, following are the summary of key findings: Firstly, despite of being more than two decades in literature, most studies are still emphasizing on the conceptual or fundamental works, which is not surprising since "the rapidly increasing literature on roadmapping itself is presented in terms of a taxonomy for classifying roadmaps, in terms of both organizational purpose and graphical format" (Phaal, Farrukh, & Probert, 2004, p. 5). Secondly, there were almost 1:1 ratio between journals and conferences, suggesting their co-development functions on technology roadmapping. Thirdly, Technological Forecasting and Social Change is the top journal for technology roadmapping, and continue to dominate in the recent years. Fourthly, PICMET maintained to be the top conference, while IEEE appeared to be the top organizer. Fifthly, studies on international context were started significantly during the first decade of 21st century (from 2001 to 2010), but have seen to slow down in the recent time-periods (2011-2015). Sixthly, the emphasis at national level was only begun during 2001-2005 time-periods. Although China is leading the current numbers of studies, the overall focus are still weighted towards developed countries. Seventhly, all studies on organizational context were dominated by the big corporations originating from developed countries, such as Motorola and Siemens. Lastly, key themes of studies were mainly interested on the technological related topics, such as ICT and energy. All of these trends are expected to continue in the future. However, due to recent development in literature, future studies should pay attention on the potentials of SMEs, developing countries, and non-technological related topics.

LIMITATIONS

Firstly, the list of references was taken from a single source of database in Phaal (2015). Although the advantage is that the quality and consistency levels of references are rest assured, the drawback is that this single source might have been recording only selective references. From the statistical point-of-view, these references therefore should be best treated as samples. Secondly, the numbers of publications recorded in the recent time-periods (2011-2015) could have displaying lower than the actual figures due to some reasons, such as where the recent articles only published after Phaal (2015). As a result, the statistics for 2011-2015 time-periods should be interpreted as accurate only in the context of this study. Thirdly, the decision to analyze the information in references instead of the contents is taken since the bibliometric analysis is sufficient to achieve the objectives of this study. Besides that, this methodology is the best way to analyze hundreds of articles with lesser effort in shorter time. Nevertheless, this methodology is relying heavily on the accuracy of information in the article titles. Therefore, the quality of findings at representing the trends in technology roadmapping is depended on the quality of article titles. Lastly, most of the articles were found written with generic titles, in which they cannot be identified into any classifications since there was no further information that can be used to details out the exact discussion of the topics. As a result, they were treated irrelevant and left undiscussed on certain classifications.

CONCLUSION

Technology roadmapping is a technique to capture information on evolving technology. As time passing by, hundreds of studies have been recorded in literature, which make this discipline of study has well established in time. With abundant of publications, this study has attempted to identify the trends in technology roadmapping by analyzing the references with bibliometric analysis. At first, there was huge numbers of references written with generic titles, which suggests the discussions on technology roadmapping are still dominated by the general topics. In details, this study has found balanced numbers of articles published in both journals and proceedings. Notwithstanding that the analysis have found high variety of journals and proceedings, most articles were either published in Technological Forecasting and Social Change or presented in PICMET. Although the list of references was taken from a single source of database written in English, which has increased the consistency and quality of references, doing this has also limited the numbers of data to be analyzed. Nevertheless, since most studies were emphasized on developed countries, big corporations, and technological related themes, it was recommended that future studies should shift the focus on the other way around.

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