

A Hybrid Roadmapping Method for Technology Forecasting and Assessment: A Case Study in an Information and Communication Technology Company

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Abstract--Technology roadmapping is an indispensable method for aligning closely between strategic objectives and technology management, especially technology-intensive enterprises. It is interesting to note that most companies are pursuing technology roadmapping approaches is very compelling, but the normal perspective for most companies is from inside to out which they start by looking at their own organization. To address the limitations found in the existing methods, this paper aims to develop a hybrid roadmapping method (HRMM) by incorporating two inside-out and outside-in perspectives for technology forecasting and assessment which provides companies with fresh insights for strategic innovation and technology planning. The HRMM is composed of four main steps which include preliminary discussion, inside-out roadmapping, outside-out roadmapping and follow-up discussion, respectively. It has been developed to provide a roadmap for strategic and innovation planning in inside-out and outside-in perspectives. The capability of the HRMM is realized through a case study conducted in the Information and Communication Technology (ICT) Industry and encouraging results have been obtained.

I. INTRODUCTION

Changing technology, driven forward by innovation, affects everybody's business. Technology is a primary cause of change and the key to productivity and change as well as change is a fact of life [39]. Some elements of the challenge posed by technology, such as shortening of product life cycles [39], [23] as well as increasing technological change [43], pace of technology development [34], complexity of technology [34], innovation speed [22], [25], [33] and speed of the diffusion of innovations [26]. Allocating the management of resource into the right technology and innovation is one of the challenges for innovation and technology-intensive enterprises. Opportunities to innovate with new technologies are abound, but only those who can adapt to the unforeseen changes will be really successful. Understanding different dimensions of the technological change is complex and uncertain. In the world of rapid change and global competition, the organizations could be able to forecast and assess technological change to obtain competitive advantage.

A. Viewpoint: inside-out vs outside-in

Smart organizations do not wait for change to happen but proactively monitor and take advantages of changing environments, new/potential technologies, and new innovations. The normal perspective for most organizations is from inside to out as shown in Fig. 1. They start by looking at

their own organization and then focusing on their own customers, competitors, technologies and resources within their own business arena. In the inside-out perspective, it may be barely satisfactory to plan market activities for the next few years in a less competitive and stable environment. If the focus is on long-term business development (i.e. product or technology development) in a more competitive, complex and rapid changing environment, the inside-out perspective may be inadequate for this environment to make the organization easily to predict changes in the global marketplace that have not already become obvious or mature.



Fig. 1 Inside-out perspective

To anticipate these changes, it is necessary to start by looking at the driving forces that may have an impact affecting the business development of the organization. Long-term development in the business arena greatly depends on driving forces in the surrounding world. The outside-in perspective [42], [27] is highly recommended for these organizations to look into the driving forces behind the changes deeply, as well as to track and analyze trends regularly in the surrounding world as shown in Fig. 2.



Fig. 2 Outside-in perspective

To express these two perspectives in terms of proactiveness, most organizations mainly focus on the present status (i.e. inside-out perspective) to solve their existing problems and treat present problems, but not focus on future to anticipate future needs and shape the future (i.e. outside-in perspective). Effective organizations may proactively make a big step in managing from the future constantly. Managing from the future will encourage the new ideas, develop the flexible processes, and invest in the management of knowledge and technology that will allow the organizations not only to adapt and survive, but to create the future. To well-equip the organizations for the future, there may be an opportunity to drive the organizations from the cleaner positions (i.e. clean acute problems and treat present problems) to a shaper role (i.e. anticipate future needs and shape the future). There are four levels of proactiveness which are illustrated in Fig. 3 (adapted from [27]).

B. Technology roadmapping

Technology roadmapping is one of the popular tools for managing new and potential technologies in the technology planning and development. The use of technology roadmapping becomes more widespread in recent decades. By leveraging the technology roadmapping process, a technology roadmap is generated which identifies alternate technology “roads” for meeting certain performance objectives. A single path may be selected and a plan is developed. If there is high uncertainty or risk, then multiple paths may be selected and pursued concurrently. The roadmap identifies precise objectives and helps to focus resources on the critical technologies that are needed to meet those objectives [15].

In other words, technology roadmap is functioned as a combination of maps and radar charts to show what the future is going to be and what obstacles will come out. In many

situations, company’s ideas are always bounded by what they know but ignoring what they do not know. Technology roadmapping facilitates users to make decisions by comprehensively considering various factors such as market, business, product, technology, resource, etc [35], [36]. By using multi-layer graphical representation of a plan, the roadmap is used to link up all the factors to better understand the relationship between market objectives and technology development based on its flexible layout which aligns with a time frame [11], [35], [41], [10], [17], [36], [32].

Initially, the value of the technology roadmaps for innovation lies in the recommendation of new technologies and products based on the evolution of existing technologies and products. The use of technology roadmaps came to the forefront with Motorola in the late 1970s for the improvement of the alignment between product and technology [46]. Moreover, reference [21] also proposed four key areas of the roadmap, such as science/technology roadmaps, industry roadmaps, product/technology roadmaps and product roadmaps.

Subsequently, the technology roadmapping method was widely adopted by government, academic and research institutions and many different industry sectors, particularly for large technology-intensive firms in the consumer electronics, aerospace and defense sectors, and then spreading to many other areas [18], [34], [2], [31], [7], [29], [4], [36], [3], [16], [5], [32]. Moreover, some researchers provided insight into roadmapping disruptive technologies [14], [24], [44], [45] and assessing emerging technologies [28], [12], [19], [8], [31], [47], [13], [37], [38]. Evidence shows that technology roadmapping enhanced the integration between business strategy and technology management which is very compelling, and most of the researchers applied exploratory qualitative approaches based on case studies.

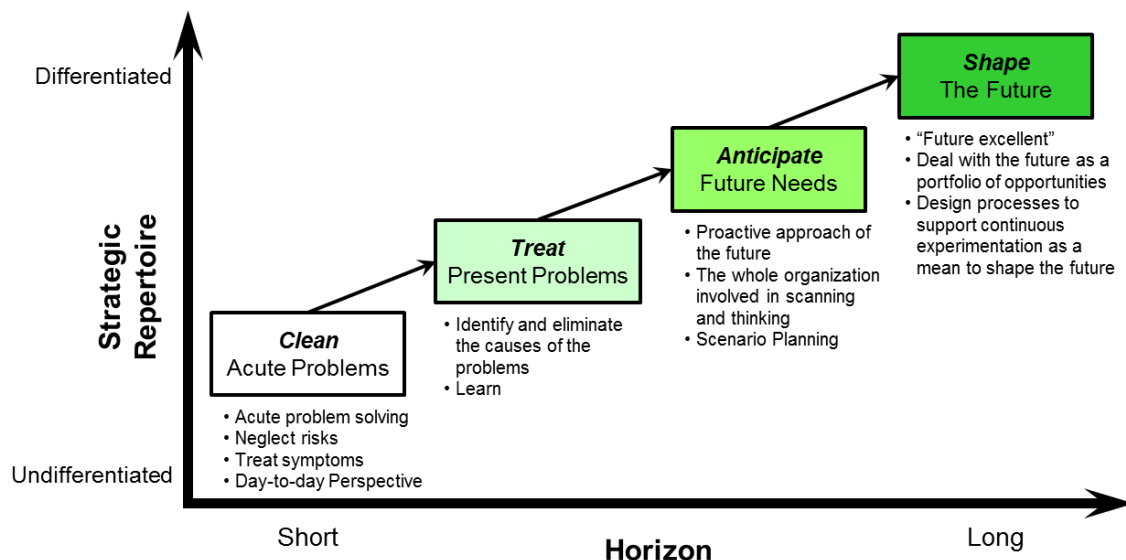


Fig. 3 Four levels of proactiveness: from cleaner to shaper (adapted from [27])

C. Summary

In this section, the normal viewpoint of the organization and the state of art of technology roadmapping for strategic innovation and technology planning are reviewed and discussed, respectively. On the whole, the existing methods help considerably for decision makers and solution seekers in the organization to link strategy to product plans to technology plans. However, they are a number of limitations which include: -

- (i) Most organizations concern themselves with their customers, competitors, technologies, resources and business arena from inside-out perspective, not outside-in perspective.
- (ii) Existing methods of technology roadmapping are workshop-oriented which involve groups of individuals with varying degree of cross-functional expertise in an organization or industry sector. The participants need to spend lots of time in order to get through the results. It is time-consuming and the qualities of the results heavily rely on the participants' knowledge, experience and opinions.
- (iii) Most of the studies demonstrated that technology roadmapping was implemented successfully in case by case. However, there is lack of quantitative measures for evaluating the performance of roadmap's outcomes.

In order to address the limitations found in the existing methods, this paper aims to develop a hybrid roadmapping method (HRMM) by incorporating two different perspectives

(i.e. inside-out and outside-in) for technology forecasting and assessment which provides companies with fresh insights for strategic innovation and technology planning. The outside-in approach aims at addressing external trend and driver landscape and evaluating the performance of roadmap's outcomes whereas the inside-out approach is concerned with technology management implementing the corporate strategy. The hybrid approach combines inside-out and outside-in by involving stakeholders and establishing a management approach in which roadmap is integrated. By leveraging the proposed method, a series of roadmaps generated based on the frameworks of the methodologies. The capability of the method is demonstrated through a case study conducted in an Information and Communication Technology (ICT) company.

II. HYBRID ROADMAPPING METHOD

A hybrid roadmapping method (HRMM) is proposed to design and develop a series of technology roadmaps for technology forecasting and assessment in inside-out and outside-in perspectives. The framework and information flow of the hybrid roadmapping method (HRMM) are shown in Fig. 4 and Table 1, respectively. As shown in Fig. 4, the HRMM is composed of four main steps which include preliminary discussion, inside-out roadmapping, outside-out roadmapping and follow-up discussion, respectively. They are conducted to develop a roadmap for strategic and innovation planning in inside-out and outside-in perspectives.

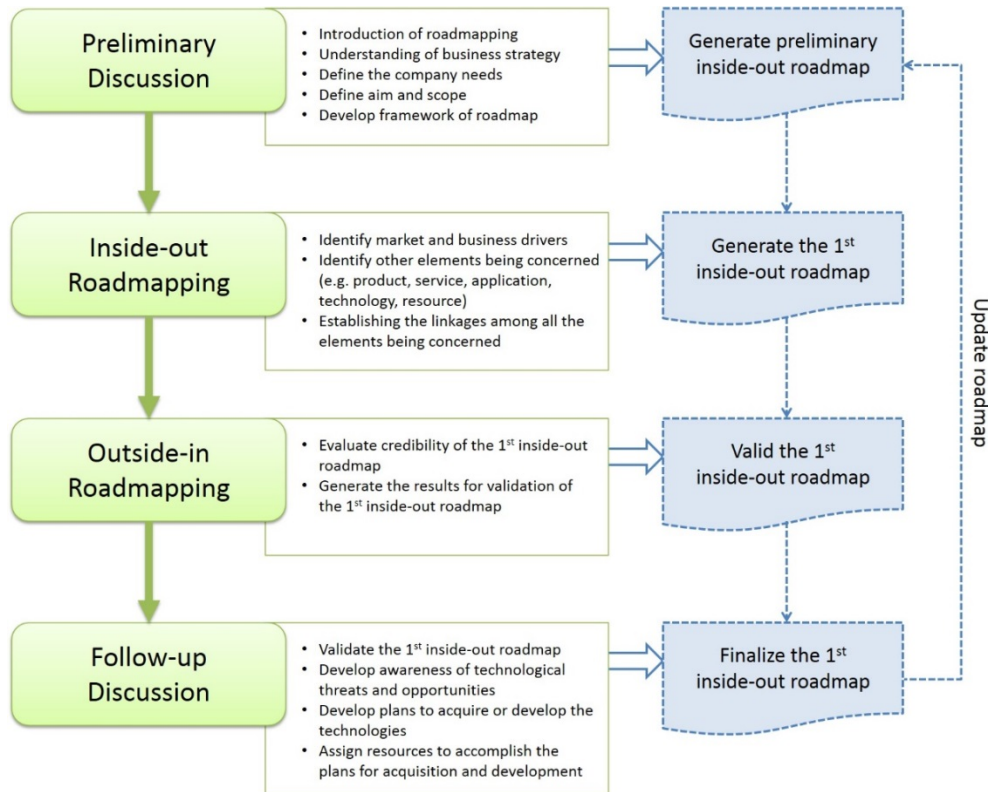


Fig. 4 Framework of the hybrid roadmapping method in inside-out and outside-in perspectives

TABLE 1 INFORMATION FLOW OF THE HRMM

	Main Step	View	Information Type	Method	Output of Roadmap
1	Preliminary Discussion	• Inside-out • Outside-in	• Primary data • Secondary data	• Face-to-face discussion • Information retrieval • Information extraction	• Develop framework of roadmap • Generate preliminary inside-out roadmap
2	Inside-out Roadmapping	• Inside-out	• Primary data	• Face-to-face discussion • Brainstorming	• Generate the first inside-out roadmap
3	Outside-in Roadmapping	• Outside-in	• Secondary data	• Information retrieval • Information extraction • Keyword search	• Generate the result of external technology intelligence for validation of the first inside-out roadmap
4	Follow-up Discussion	• Inside-out • Outside-in	• Primary data • Secondary data	• Face-to-face discussion	• Finalize the first inside-out roadmap

The preliminary discussion aims at having an understanding of company in terms of (a) company needs, (b) driver landscape and external trends addressed as well as (c) the existing business strategy. As shown in Table 1, these three types of information are elicited by different approaches such as face-to-face discussion, information retrieval and extraction for prerequisite preparation of inside-out roadmapping. The significant outcomes of the discussion well defined aim and scope of the roadmap and a framework of the roadmap are subsequently developed based on corporate need and strategy. Hence, a preliminary inside-out roadmap is generated by the primary data which are the information elicited in the preliminary discussion and published company information (i.e. company profile, press releases, annual report, etc.) for inside-out roadmapping use.

The preliminary inside-out roadmap is validated by the participants from the beginning of the inside-out roadmapping. On the basis of the validated preliminary inside-out roadmap, the inside-out roadmapping is then conducted with the participants using face-to-face discussion in inside-out perspective. According to the framework of the roadmap, all the elements being concerned (e.g. market and business drivers, product, service, application, technology, resource) are identified and the linkages among all the elements being concerned are established.

On the completion of the inside-out roadmapping, the first inside-out roadmap is also generated by the participants and the content on the roadmap expresses their ideas and opinions to the future plan in inside-out perspective (i.e. what future market segment they can serve).

Outside-in roadmapping is a validation stage for evaluating the credibility of the first inside-out roadmap in secondary data analysis. To be precise, the context of roadmap (i.e. each tag on the roadmap) is validated by external technology intelligence through search engine, patent and publication databases to see whether the similar ideas of solutions/ applications/ services/ technologies were advanced by someone (i.e. competitor). If similar idea is found, the detail of the similar idea is collected for validation purpose. On the completion of the outside-in roadmapping, the results of external technology intelligence are generated for the validation of the first inside-out roadmap.

Follow-up discussion is subsequently conducted in two

parts i.e. (a) validation of the first inside-out roadmap using face-to-face discussion according to the results generated by outside-in roadmapping, and (b) the development of awareness of technological threats and opportunities. For example, the company anticipates a certain solution appearing in the medium term, but their competitors already introduce similar solution in earlier time, the company may then adjust their technology development strategy. The last but not the least, a valid inside-out roadmap is completed which is used to develop strategic plans and assign resources for technology development and acquisition.

III. TRIAL IMPLEMENTATION AND CASE STUDY

To realize the capability of the hybrid roadmapping method (HRMM), a case study was conducted in an Information and Communication Technology (ICT) company in Hong Kong. A target company called Hong Kong RFID Limited (HK-RFID). Since its establishment in 2004, HK-RFID becomes a leading Radio Frequency Identification (RFID) solution provider with headquarter in Hong Kong which mainly provides RFID solutions and consultancy services for efficiency enhancement and location tracking technologies of assets (i.e. luxury and important assets) reaching out to the clients worldwide.

In 2005, HK-RFID was an incubatee of Hong Kong Science and Technology Park's Incu-Tech Programme and graduated in 2008. HK-RFID is also hardware provider that possesses R&D and production capabilities to design and manufacture of RFID hardware and wireless system, such as tags and readers (i.e. passive and active) for applying in various industries (e.g. environmental monitoring, anti-counterfeit, visitor counter). Most of their clients are business-to-business (B2B) clients in various sectors such as Government, public sector and financial service sector, etc. Representative clients include the Commerce and Economic Development Bureau as well as Hong Kong Housing Authority (HA) of the Government of the Hong Kong Special Administrative Region (HKSAR), Hong Kong Mass Transit Railway (MTR) Corporation, Hong Kong Convention and Exhibition Centre (HKCEC), Hong Kong and Shanghai Banking Corporation Limited (HSBC), Sino Land Company Limited, etc.. Milestones of the development of the HKRFID

are shown in Fig. 5 (adopted from [20]).

HK-RFID is currently using the method of brainstorming to generate ideas about the future market, application and technology for strategic planning during the regular meeting. Encouraging by top management, the regular meeting is conducted within the company and involves a variety of employees from different departments such as business, sales and marketing, R&D, engineering, production and manufacturing, etc.. Even though taking much effort to generating ideas for future development plan, they are still facing several challenges which are summarized as follows:

- (i) Lack of time-effective and systematic tool to plan the long-term corporate development
- (ii) Hard to keep balance of commercial and technological functions
- (iii) Lack of quantitative measures for evaluating the performance of roadmap's outcomes

In summary, background description of the target organization provides a clear illustration of their existing method for strategic planning for dealing with the challenges in technology forecast and assessment. This case study is used to demonstrate the capability of the hybrid roadmapping method for technology forecasting and assessment so as to assist the target organization to develop the inside-out roadmap of technology development (i.e. RFID technology) out to 10-year horizon (i.e. 2013 – 2023).

IV. RESULT AND DISCUSSION

In the section, the result of the case study is presented and discussed. During the preliminary discussion, the proposed methodology of hybrid roadmapping was presented to the organization. According to the needs of the target

organization, an inside-out roadmap of technology development of RFID out to 10-year horizon (i.e. 2013 – 2023) was developed in the study based on the proposed methodology. The framework of the roadmap was designed and developed which consists of three major elements in row, such as (a) trend and driver, (b) application and (c) technology.

According to the element trend and driver, internal corporate development with micro view and external environment with the macro view were identified as trends and drivers of business and market, respectively. On the basis of the company business solutions, three significant applications were chosen for technology forecasting and assessment, such as Healthcare Management, Location Tracking and Physical Assets Management (PAM). In the technology layer, four core technologies were identified including identification technology, sensor technology, communication technology and security technology which are most influential to these application areas in the whole period between 2013 and 2023.

For well preparation of inside-out roadmapping, the published company information was collected to better understand the company background and business strategy in short and medium terms, such as company website, company catalog, press release and interview scripts were released by media (i.e. newspaper, TV program). A preliminary inside-out roadmap was generated by the primary data analysis according to the information elicited in the preliminary discussion and published company information as shown in Fig. 6. A brief description of preliminary inside-out roadmap was delivered at the beginning of the inside-out roadmapping. Afterward all the captured information which was put on the preliminary inside-out roadmap was validated and confirmed by the company representative.

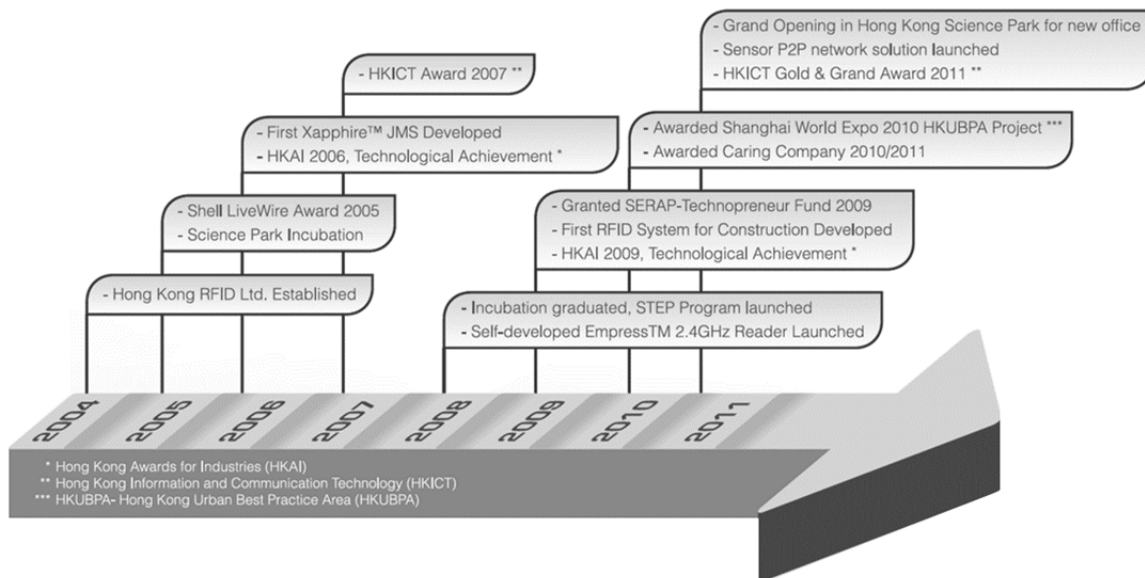


Fig. 5 Milestones of Hong Kong RFID Limited (HK-RFID) (adopted from [20])

On the basis of the preliminary inside-out roadmap, inside-out roadmapping was then conducted using group discussion in inside-out perspective. Three major elements including trend and driver, application and technology were discussed in short, medium and long terms, respectively. Afterward the first inside-in roadmap of future technological development of RFID out to 10-year horizon was developed based on the proposed methodology, as illustrated in Fig. 7.

Outside-in roadmapping was a validation stage for evaluating the credibility of the first inside-out roadmap by

secondary data analysis. Two examples of validations were demonstrated in the following sections. It is recalled that due to the restriction from sensor vendors, the company was not willing to further develop the RFID solution of healthcare management without very strong market demand, but they anticipated that the RFID solution for heartbeat and blood pressure monitoring of the elderly and the disabled will be developed and implemented in the medium term between 2018 and 2019 due to the future ageing population in Hong Kong.



Fig. 6 Preliminary inside-out roadmap

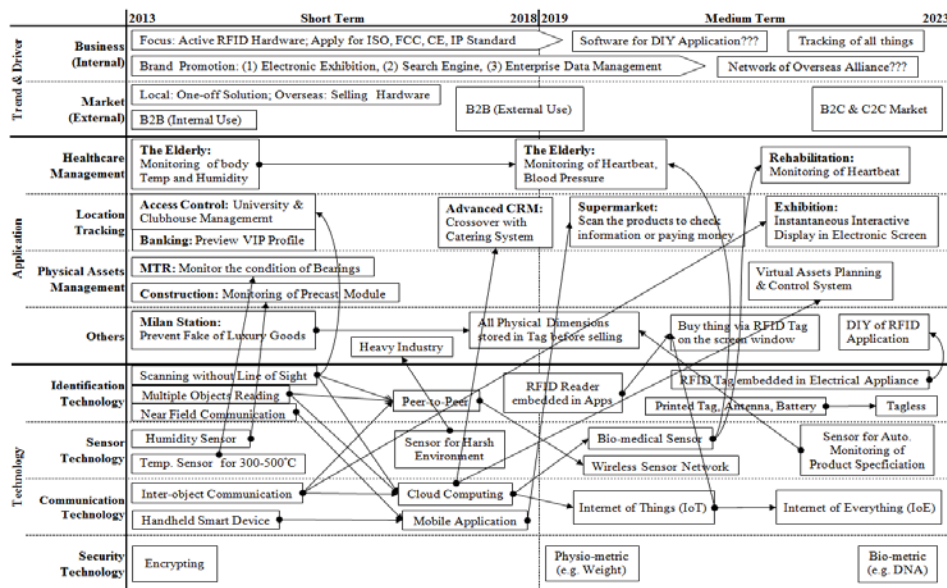


Fig. 7 The first inside-out roadmap

By conducting the secondary data analysis, reference [30] developed the similar RFID solution for wireless heartbeat monitoring. While the outdoor wireless healthcare monitoring with RFID-enhanced video sensor networks was also developed [2]. According to the above validation of secondary data, the solution for heartbeat and blood pressure monitoring of the elderly was suggested to develop and implement in the short term, instead of medium term as illustrated in Fig. 8.

Another example was about the solution of location tracking in supermarket. By applying mobile technology (i.e. mobile device), scanning the product information and settling payment during the shopping were proposed to implement at Toenisvorst in western Germany, respectively [9], [6]. As shown in Fig. 9, it is a reason why the solution of location tracking in supermarket was suggested to develop and implement in the short term, instead of medium term.

In summary, the company expressed that the results of the study were useful and practical for the companies to provide fresh insights for strategic innovation and technology planning in inside-out and outside-in perspectives. This new approach also combined their common practices of discussion methods such as brainstorming, face-to-face interview and group discussion so that they made less effort to adapt the new approach, but can integrate all of the work done into this single-page and visual technology roadmap through this systematic process. Especially, the results of the validation provided a quick view on what others were already done and vice versa and they may initiate the follow up actions effectively after the completion of the roadmapping.

V. CONCLUSIONS

More technology intensive companies are increasingly paying attention to assess the possible future technology trends, identify the impacts of the changes in technology and market needs, in terms of potential threats and opportunities, especially for disruptive technologies and markets. In this paper, a hybrid roadmapping method (HRMM) is proposed which attempts to incorporate inside-out and outside-in perspectives for technology forecasting and assessment which provides companies with fresh insights for strategic innovation and technology planning. The HRMM is

composed of four main steps including preliminary discussion, inside-out roadmapping, outside-out roadmapping and follow-up discussion, respectively. By leveraging the secondary and primary data analysis, the outside-in approach aims at addressing external trend and drivers landscape in the preliminary discussion, and evaluating the credibility of roadmap's outcomes in the outside-in roadmapping and follow-up discussion whereas the inside-out approach is concerned with striking a good balance between strategy planning and technology development in the implementation of the corporate strategy. The HRMM was trial implemented in an Information and Communication Technology (ICT) company to demonstrate the capability of the HRMM. By adopting the HRMM, the roadmap of technology development (i.e. RFID technology) out to 10-year horizon (i.e. 2013 – 2023) was generated for strategic innovation and technology planning in inside-out and outside-in perspectives. Moreover, the results of external technology intelligence are also generated for evaluating the performance of the roadmap.

As compared with the existing method they used, the company made positive comment about the proposed methodology which is relatively effective and ease-to-use. Moreover, it not only allows the company to externalize their insight of future for strategic innovation and technology planning as a one-off task, but also encourages them to keep updating of the roadmap in the future. The development of the HRMM not only saves time and staffing but also enables an organization to keep pace with the knowledge cycle in technology innovation and development. This is particularly important when technology intensive enterprise attempts to manage R&D activities and strategic planning for technology management.

For future work, the proposed methodology should be evaluated on a large number of technology-intensive companies to verify the performance. The roadmapping may be recommended to be conducted within the company and involve a variety of employees, rather than a representative of the company. The proposed potential respondents include individual, teams, and departments, instead of the company as a whole. Furthermore, various technology management techniques (i.e. PEST, SWOT analysis) may be also taken

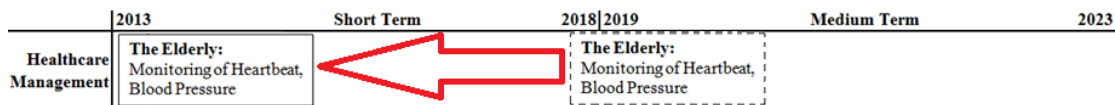


Fig. 8 Example of validation for solution in Healthcare Management

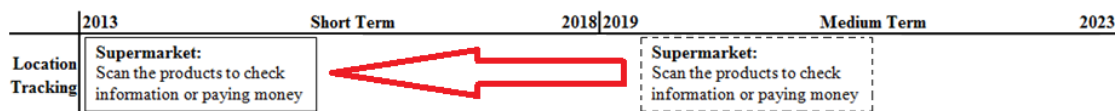


Fig. 9 Example of validation for solution in Location Tracking

into consideration to combine with technology roadmapping for technology forecasting and assessment to assist the companies to explore business opportunities for innovating technology via the proposed methodology.

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REFERENCES

- [1] Abe, H., T. Ashiki, A. Suzuki, F. Jinno and H. Sakuma, "Integration studies of business modeling and roadmapping methods for innovation support technology (IST) and its practical application to real-world-cases," in *Management of Engineering and Technology, Portland International Center for*, 2007.
- [2] Alemdar, H., Y. Durmus and C. Ersoy, "Wireless healthcare monitoring with RFID-enhanced video sensor networks," *International Journal of Distributed Sensor Networks*, pp. 1-10, 2010.
- [3] Amadi-Echendu, J., O. Lephauphau, M. Maswanganyi and M. Mkhize; "Case studies of technology roadmapping in mining," *Journal of Engineering and Technology Management*, vol. 28, pp. 23-32, 2011.
- [4] Bagheri, S. K., H. Nilforoushan, M. Rezapour and M. Rashtchi; "A new approach to technology roadmapping in the open innovation context: The case of Membrane technology for RIPI," *Journal of Science & Technology Policy*, vol. 2, pp. 81-91, 2009.
- [5] Carvalho, M., A. Fleury and A. P. Lopes; "An overview of the literature on technology roadmapping (TRM): Contributions and trends," *Technological Forecasting and Social Change*, vol. 80, pp. 1418-1437, 2013.
- [6] Chibber, K., "Is this the supermarket of the future", Retrieved 20/3/13 World Wide Web, <http://www.bbc.co.uk/news/business-12310809>.
- [7] Daim, T.U. and T. Oliver; "Implementing technology roadmap process in the energy services sector: A case study of a government agency," *Technological Forecasting and Social Change*, vol. 75, pp. 687-720, 2008.
- [8] Dissel, M., R. Phaal, C. Farrukh and D. Probert, Value Roadmapping: A structured approach for early stage technology investment decisions, in *Technology Management for the Global Future, 2006. PICMET 2006*, 2006.
- [9] Bosma, T., "Future supermarket in Germany", Retrieved 20/3/13 World Wide Web, http://www.extendlimits.nl/nieuws/artikel/future_supermarket_in_germ_any/.
- [10] Farrokhsad, B., C. Kern and M. D. Vries; "Innovation business plan at Siemens: portfolio-based roadmapping to convert promising innovation projects into concrete successes", *International Journal of Technology Intelligence and Planning*, vol. 4, pp. 153-164, 2008.
- [11] Farrukh, C., R. Phaal and D. Probert; "Technology management - integrating technology into business planning," in *Proceedings of the Eleventh Annual Conference of the Production and Operations Management Society (POM2000)*, 2000.
- [12] Fleischer, T., M. Decker and U. Fiedeler, "Assessing emerging technologies - Methodological challenges and the case of nanotechnologies", *Technological Forecasting and Social Change*, vol. 72, pp. 1112-1121, 2005.
- [13] Ford, S., M. Routley, R. Phaal, E. O'Sullivan and D. Probert; "The dynamics of industrial emergence: Insights from commercial inkjet printing", in *Emerging industries: Theory and Evidence Showcase Symposium, Academy of Management Annual Meeting*, 2011.
- [14] Galvin, R.; "Roadmapping - practitioner's update", *Technological Forecasting and Social Change*, vol. 71, pp. 101-103, 2004.
- [15] Garcia, M. L. and O. H. Bray, "Fundamentals of technology roadmapping," Sandia National Laboratories, Report, 1998.
- [16] Geum, Y., S. Lee, D. Kang and Y. Park; "Technology roadmapping for technology-based product-service integration: A case study", *Journal of Engineering and Technology Management*, vol. 28, pp. 128-146, 2011.
- [17] Goenaga, J. M. and R. Phaal; "Roadmapping lessons from the Basque country", *Research Technology Management*, vol. 52, pp. 9-12, 2009.
- [18] Groenvel, P.; "Roadmapping integrates business and technology", *Research Technology Management*, vol. 40, pp. 48-55, 1997.
- [19] Holmes, C. and M. Ferrill; "The application of operation and technology roadmapping to aid Singaporean SMEs identify and select emerging technologies", *Technological Forecasting and Social Change*, vol. 72 pp. 349-357, 2005.
- [20] Hong Kong RFID Limited, "Company profile of Hong Kong RFID Limited", Retrieved 4/1/14 World Wide Web, http://media.wix.com/ugd/f23250_e7c87b2d712f7a8d60672b5b4754cb96.pdf.
- [21] Kappel, T. A.; "Perspectives on roadmaps: how organizations talk about the future", *Journal of Product Innovation Management*, vol. 18, pp. 39-50, 2001.
- [22] Kessler, E. and P. Bierly; "Is faster really better? An empirical test of the implications of innovation speed", *Engineering Management, IEEE Transactions on*, vol. 49, pp. 2-12, 2002.
- [23] Kessler, E. H. and A. K. Chakrabarti; "Innovation speed: A conceptual model of context, antecedents, and outcomes", *Academy of Management Review*, vol. 21, pp. 1143-1191, 1996.
- [24] Kostoff, R.N., R. Boylan and G. R. Simons; "Disruptive technology roadmaps", *Technological Forecasting and Social Change*, vol. 71, pp. 141-159, 2004.
- [25] Langerak, F. and E. Hultink; "The impact of new product development acceleration approaches on speed and profitability: lessons for pioneers and fast followers", *Engineering Management, IEEE Transactions on*, vol. 52, pp. 30-42 (2005).
- [26] Lee, H., K. G. Smith and C. M. Grimm; "The effect of new product radicality and scope on the extent and speed of innovation diffusion", *Journal of Management*, vol. 29, pp. 753-768, 2003.
- [27] Lindgren, M. and H. Bandhold; *Scenario planning: The link between future and strategy*. Palgrave Macmillan, 2009.
- [28] Linton, J. D.; "Determining demand, supply, and pricing for emerging markets based on disruptive process technologies", *Technological Forecasting and Social Change*, vol. 71, pp. 105-120, 2004.
- [29] Lischka, J.-M. and H. G. Gemunden; "Technology roadmapping in manufacturing: A case study at Siemens AG", *International Journal of Technology Intelligence and Planning*, vol. 4, pp. 201-214, 2008.
- [30] Mal, S.; "RFID-enabled wireless heart monitoring", Retrieved 1/4/13 World Wide Web, <http://www.winmec.ucla.edu/rfid/course/2007f/RFID-Enabled%20Wireless%20Heart%20Monitoring.pdf>.
- [31] Martin, H. and T. Daim; "Technology roadmapping through intelligence analysis: Nanotechnology," in *Management of Engineering and Technology, Portland International Center for*, 2007.
- [32] Moehrl, M.G., R. Isenmann and R. Phaal; *Technology roadmapping for strategy and innovation: Charting the route to success*. Springer Berlin Heidelberg, 2013.
- [33] Parry, M. E., M. Song, P. C. de Weerd-Nederhof and K. Visscher; "The impact of NPD strategy, product strategy, and NPD processes on perceived cycle time", *Journal of Product Innovation Management*, vol. 26, pp. 627-639, 2009.
- [34] Phaal, R., C. Farrukh and D. Probert, "Technology management process assessment: A case study", *International Journal of Operations & Production Management*, vol. 21, pp. 1116-1132, 2001.
- [35] Phaal, R., C. Farrukh and D. Probert; *T-plan: The fast start to technology roadmapping. Planning your route to success*. University of Cambridge, Institute for Manufacturing, 2001.
- [36] Phaal, R., C. Farrukh and D. Probert; *Roadmapping for strategy and innovation: Aligning technology and markets in a dynamic world*. University of Cambridge, Institute for Manufacturing, 2010.
- [37] Phaal, R., E. O'Sullivan, M. Routley, S. Ford and D. Probert, "A framework for mapping industrial emergence", *Technological Forecasting and Social Change*, vol. 78, pp. 217-230, 2011.

- [38] Phaal, R., M. Routley, N. Athanassopoulou and D. Probert; "Charting exploitation strategies for emerging technology", *Research-Technology Management*, vol. 55, pp. 34-42, 2012.
- [39] Porter, A. L., S. W. Cunningham, J. Banks, A. T. Roper, T. W. Mason and F. A. Rossini; *Forecasting and Management of Technology*. Wiley, 2011.
- [40] Qualls, W., R. W. Olshavsky and R. E. Michaels; "Shortening of the PLC - An empirical test", *Journal of Marketing*, vol. 45, pp. 76-80, 1981.
- [41] Rinne, M.; "Technology roadmaps: Infrastructure for innovation", *Technological Forecasting and Social Change*, vol. 71, pp. 67-80, 2004.
- [42] Savioz, P.; *Technology intelligence: Concept design and implementation in rechnology based SMEs*. New York: Palgrave Macmillan, 2004.
- [43] Sood, A. and G. J. Tellis; "Technological evolution and radical innovation", *Journal of Marketing*, vol. 69, pp. 152-168, 2005.
- [44] Vojak, B. A. and F. A. Chambers; "Roadmapping disruptive technical threats and opportunities in complex, technology-based subsystems: The SAILS methodology", *Technological Forecasting and Social Change*, vol. 71, pp. 121-139, 2004.
- [45] Walsh, S. T.; "Roadmapping a disruptive technology: A case study: The emerging microsystems and top-down nanosystems industry", *Technological Forecasting and Social Change*, vol. 71, pp. 161-185, 2004.
- [46] Willard, C. H. and C. McClees; "Motorola's technology roadmap process", *Research Management*, vol. 30, pp. 13-19, 1987.
- [47] Yasunaga, Y., M. Watanabe and M. Korenaga; "Application of technology roadmaps to governmental innovation policy for promoting technology convergence", *Technological Forecasting and Social Change*, vol. 76, pp. 61-79, 2009.