Competition-driven figures of merit in technology roadmap planning

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Abstract **Based on the intense technological environment requiring early and accurate analysis, this paper proposes competition based on figures of merit analysis in the context of technology planning and roadmapping. Competitive based figures of merit are used in this context to benchmark the evolution of technology in an industrial sector while accounting for competitive forces, using a game theoretical approach. The automotive industry is studied as a case of a highly competitive commercial enterprise. By the application of several tools for the preliminary analysis of the competition level, the competition driven FOMs are distinguished.**

Keywords ***technology roadmap planning; game-theoretic planning; competitive technology intelligence; competition-driven FOMs.***

I. INTRODUCTION

Currently, a rapid technology evolution takes place and makes main enterprises apply various technology planning and roadmapping frameworks to maintain their leading positions and increase their competitiveness. It is known that technological changes play a role in changes of rules of competition and structure within one industry. They are the regulators, destroying the competitive advantage of even well-established firms and pushing others to the forefront [1]. Technology progress is happening in terms of tough competition between major players, that affects strategic decisions, system engineering, and model configurations.

Therefore, it is important to apply technology planning techniques that take into account the dynamic environment of company. It is done in the game-theoretic technology planning framework [2]. The methodology analyzes an existing competition between two companies as a game model. The framework evaluates the past and the predicted technological models described by a number of figures of merit.

A figure of merit (FOM) is an attribute used to characterize and evaluate performance of a technical model or a system relative to its alternatives. It is described by its name, symbol, and unit of measure. Two or more FOMs form a technology tradespace presented by a set of data points. Evaluation of different technical models generates the points and demonstrates the technological change and trends [3].

As technologies continuously evolve, the need for sufficient information on recent developments has become a concern in highly competitive economic environments. The identification and tracking of technology trends in FOMs are crucial for companies in industry to develop a successful strategic plan focusing on future research and product development efforts [4].

To successfully compete, enterprises should conduct an accurate and convincing technology planning activities. As the game-theoretic framework evaluates a technology competition in 2-dimensional tradespace, the accuracy depends on the FOMs chosen for the analysis. The choice should be rationalized by presence of technological 'race' because the competition drives the technological changes in some cases. It is needed to study the level of competition separately for different FOMs, for example, using the CI and CTI methods.

This paper investigates the topic of competition-driven FOMs that can be more sensitive to the ongoing competition and, therefore, more dependent on the opponent's current level. It examines the degree of influence and relationship in the race of two rival firms and the evolution. The reason is to improve the game simulation in the game-theoretic technology roadmap planning framework and shape the process of system engineering in a more competition oriented way.

The paper is organized as follows: section II gives an overview of competition assessment, competitive and technical intelligence and the game-theoretic technology roadmap planning framework; section III introduces a concept of competition-driven FOMs and an approach for their study; section IV presents the results of the competition investigation in the automotive market on technical FOMs; section V presents the conclusions of the work.

II. LITERATURE REVIEW

This section presents a literature review on competition and its importance, as well as on competitive intelligence (CI) and competitive technical intelligence (CTI) as a common method for its investigation, and the game-theoretic technology roadmap planning framework.

A. Technology competition

Competition is essential to innovation process and capitalist economic development more generally. Technological innovations and changes have significant strategic implications for individual companies and can greatly influence industries as a whole. The firm executives in a McKinsey study commented how their firms responded either to a significant price change or to a significant innovation by a competitor that their companies found out about the significant competitive move too late to react before it hit the market [5]. The first concern of companies facing a significant competitive move is to protect their position or to try turning the situation to their advantage. It results in a 'tough race' that takes place in a particular industry. Regardless of the nature of the competitive move, companies in the high-tech and telecom sectors are faster to respond, and their responses are intended to damage their competitor's position and earnings.

Competition can lead to too much or too little R&D investment. First, if firms are unable to exclude other firms from using technology they have developed, there is a 'free rider' problem. If patents prevent direct imitation, there is likely to be a technological 'neighborhood' illuminated by the innovation that is not foreclosed by the patent. Second, it can be referred to as 'overbidding'. It arises in the early development phase as competitors are stimulated to invest for the potential rewards that will go to the patent winner. Incentives to be the first to invent, or to be first to get the patent, may induce too many firms to try to invent early. In such a competitive race, too many resources may get applied too early and be misallocated. One consequence may be that firms drop out of the industry after the patent application is disclosed [6].

However, the understanding competitive tendency of development and tradescape analysis give insights on key players and their competitiveness; R&D trends and alerts on changes resulting into R&D strategy.

B. Competitive and technical intelligence

In many literature resources, competitive intelligence and competitive technical intelligence are mentioned as an essential activity for highly-competitive markets. CI is an activity to track the direct and indirect competitors in a range of fields [7]. It became important and widely used in the 80s. Several studies have been conducted on competitive intelligence domain, but no empirical work gives a complete implemented competitive intelligence solution [8]. This concept is implemented in large and small companies, in private and public sector, and within an industrial context, but with different level of success influence [9].

The CI objectives are:

- Identifying and detecting market trends opportunities, forces, risks and threats [9];
- Processing and combining data to provide new knowledge about priority and secondary competitors (current competitive position, historical performance, strategy in different sectors, new activities, patent registration, research activity) [7];
- Processing and combining data to provide new knowledge about customers, and suppliers, and influences generated by political changes [10];
- Forecasting environment's evolutions [11];
- Maximizing revenues and minimizing expenses [12];
- Enhancing the organization's competitiveness [10];
- Developing and supporting decision-making and technology strategy processes at all levels with reducing the decision-making time [9-10];

CI gathers and processes data from different sources on competition and its leading players, market environment and transforms that data into intelligence (Fig. 1). First, publicly available competitive technical and R&D data affecting enterprise's technology strategy are collected. Second, the data are organized into competitive technical information. The final step, which involves analysis, is competitive intelligence that adds value to firm and supports decision-making.

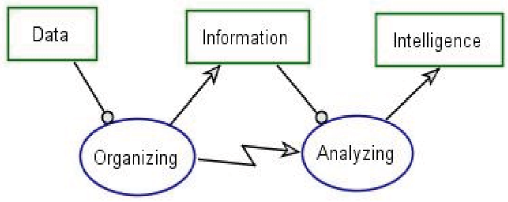

Fig. 1. Competitive intelligence model.

Competitive technical intelligence (CTI) is a research field focusing on technology trends, scientific breakthroughs and resulting impact on R&D activities [11, 13]. CTI determines the strategic effects and allows companies to anticipate the future technological trends with early identification of modifications or changes in tradespace [14].

Various strategy tools are provided in strategic management, competitive intelligence and technological innovation fields applied to CTI. They are competitive profiles, CTI database with competitor data, patent analysis, war gaming and scenario planning. The tools can be used to new product introduction programs, new technology programs, high growth programs, IP strategy, competitive product analysis, technology briefs, strategic planning.

The acquired information is used to improve the enterprise's activities devoted to technology innovation. It shows uniqueness of a competitor's technology within R&D and market landscape. For example, in recent years the demand for cell phones has multiplied in the Chinese market, where more and more cell phone manufacturing firms are emerging. Among the numerous competitors, not all of them are competitive in the same scope. Cell phone manufacturing firms need to target their key competitors and track the competitors' technical development. Competitive technical intelligence enables companies to identify where technology can deliver a competitive advantage [15].

Based on what is mentioned above, CTI can improve the accuracy of strategic planning. Enterprise's CTI strategic planning uses strategic planning tools to review and analyze the dynamic, complex and varied external technical environment and the enterprise's technical ability. The enterprise can choose and change its strategic plan based on external technology environment situation and intense rate, technical changes speed, and its CTI level [13].

C. Game theoretic approach for technology roadmap planning

The game-theoretic framework for roadmap planning [2] is based on the idea of an interdependent evolution of competitors' technical characteristics and decisions. This interdependence influences firms' technology planning and strategic processes and is the foundation of game theory. The FOM analysis that underlies the framework can be attributed to this CI and CTI based on the objectives that are pursued.

The direct competition between two engineering companies within one technology tradespace is considered to be a 2-player game. It is assumed to be a sequential game with rational players who possess perfect information on each other: the past development process and previous games in the technology tradespace. One player has a first-mover advantage. As has been mentioned above, the model assumes a tradespace of viable technology investment options mapped using two FOMs of interest and Pareto frontiers. They present the payoffs which can be obtained from alternative strategies which are shown by different product models. The whole development process is the sequential moves from one Pareto frontier to another (Fig. 2).

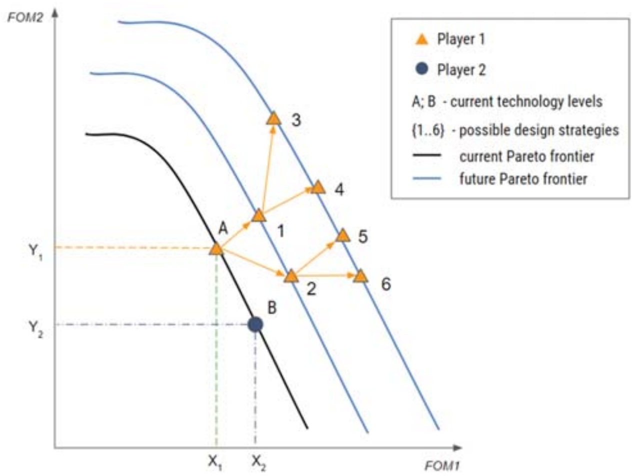

Fig. 2. Technology tradespace with development process throughout Pareto frontiers

Each year is considered to be a subgame of the whole development game and is discussed separately. The study of the subgame starts with analyzing possible payoffs and determining a Nash Equilibrium strategy for each given year. A Nash Equilibrium (NE) represents a combination of decisions where no player has an incentive to deviate from his decision. It means that each player is playing the best response to the other's strategy choice. The players cannot gain anything by choosing a different decision alternative [15].

The best-response sets over the past subgames are determined and used to forecast the future reaction points in the FOMs of interest. The selection of the alternative designs is made by projecting the predicted best responses at the 2-FOM tradespace. The technology configurations are determined as the intersections with the predicted Pareto frontiers. The result of the roadmap planning process is an optimal path throughout the future Pareto frontiers showing the possible technology evolution based on the existing engineering competition. The framework supports the decision-making process by the simulation showing possible competition outcomes.

III. CONCEPT OF COMPETITION-DRIVEN FOMS

A. Competition driven FOMs and its analysis

As the game-theoretic planning framework is focused on 2-FOM tradespace for easier interpretation, the process of FOM selection is based on the understanding of the main driving characteristics of the considered technology and models, but not all technical features are competition-driven.

The evolving external effects can influence different FOMs variously characterizing one technology. Thus, it shows a different interest of the leading competitors. It's important to be sure that the competition takes place in the considered FOMs. For example, the FOMs as product price and theoretical performance of Graphics Processing Unit (GPU) have different influences, and it can be stated that the performance FOM follows lower dependence comparing to the price FOM. If the relationship in FOM best-response sets is strong, the best-response functions give more accurate results in the reaction prediction, while the FOMs with weak competition, will provide significant errors in the model configurations. Understanding the levels of impact and relationships in the evolution and changes of FOMs helps to identify better approaches for technology development and ways to approach the technology tradespace changes earlier in the future.

For the preliminary analysis, the best-response sets of the considered enterprises are analyzed using the following methods:

Visual representation

It can be claimed on the visual representation of best-response sets that the FOM is competition-driven and is more sensitive to the actions of the competitor within one tradespace if:

1. The FOM evolution trend exists and has a direction of desired development. The FOM development trend over the years can be down-forward, up-forward or neutral (it has almost a straight trend line over specific time). Neutral characteristics do not allow to calculate the best response in separate subgames, in most cases, the other leading dominating FOMs drive them. The up- or down-forward direction means that both companies have an intention or is pushed by the competition to possess innovation in the certain technological field.

2. The separate technological trends have a similar shape and are located at a close distance, which may decrease over time. Also in the separately considered years, there are jumps over the competitors' level in comparison with the level of development of previous years. Such jumps to the competitor's level or over it show that the player has taken innovation actions and decisions to change their level.

Best response correlation analysis

The calculation of the correlation coefficient makes it possible to investigate the linear dependence of the considered best responses. It is worth noting when the trends of the players are close, their coefficient will be quite high. It is assumed that competition-driven FOMs have a strong relationship and high correlation.

If all FOMs of the considered technology have a medium or lower correlation, the ones with highest values above average can be considered as competition-driven and be used for the game-theoretic planning.

Best response regression analysis

The regression analysis is widely used for prediction and forecasting, but generally to estimate the relationship between a set of independent variables (regressors) and some dependent variable (outcome). A model of the relationship is hypothesized, and estimates of the parameter values are used to develop an estimated regression equation. The certain FOM of one player is considered as independent and analysis is done for the same FOM of another company. It will show the strength of the relationship and can be used for the further study in the game-theoretic framework. Both regression and correlation analyses can indicate only how or to what extent variables are associated with each other.

IV. RESULTS - AUTOMOBILE MARKET CASE STUDY

The automotive market is a highly competitive industry with many companies trying to lead several car segments. Two enterprises, Company A and Company B, are considered the two main players in the technology competition. The car dataset consists of ~9000 models with the main technical characteristics.

The technology tradespace is formed for two FOMs: Total maximum engine power in Hp and Average fuel consumption in l/100 km. The development of car models since 1975 is shown in Fig. 3. Both companies release more models in the lower part of the tradespace with less fuel consumption and engine power and follow quite similar development processes in the following FOMs of interest.

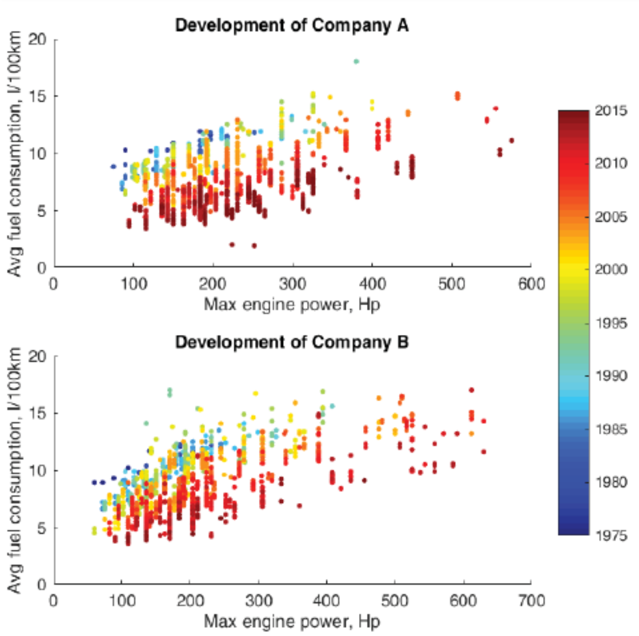

Fig. 3. Automobile technology tradespace of the considered players

The dataset contains information about the seven main characteristics of different automobile models. The levels of competition are discussed for each FOM for comparison. The players' BR sets are determined based on the whole development trend and the objective of the considered companies: as the minimum for Average fuel consumption and Acceleration, as the maximum for Total max engine power. Building the FOM BR sets over time shows the development process of firms.

As an illustrative example of such development for visual representation the best-response trends of Total max power, Average fuel consumption and Average acceleration are shown in Fig. 4. It should be mentioned the empty weight is slowly increasing over the years. It means the cars are more massive and need more powerful engines to obtain the same performance. Alternatively, the models will have less performance with the same engines leading to a decrease in acceleration. Given that over time the legislator requests a reduction on the overall CO_2 production of the fleet of cars a car-maker produces per year (in addition to the reduction of other pollutants), an overall decrease of the fuel consumption (linked to the CO_2 production) is obtained. Thus, with heavier cars and a reduction of the fuel consumption, an overall decrease in the acceleration obtained is expected shown in Fig. 4.

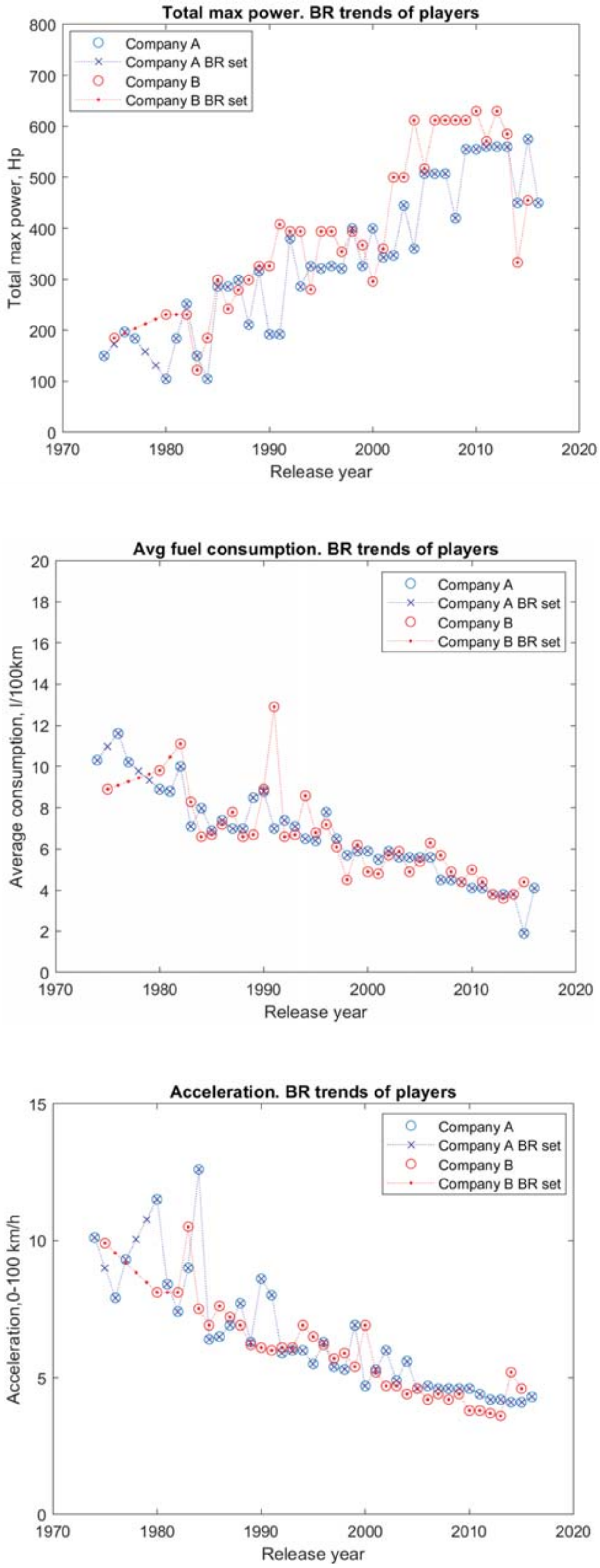

Fig. 4. Best-response trends of companies over the years.

In the visual representation, it is seen in the forms of best-response sets of Average fuel consumption and Acceleration are quite close and almost the same at some time point. It defines the high completion in these figures of merit. It is hard to conclude the leader, Company A or Company B, in these particular FOMs. The best-response trends of Total max engine power follow the same form but stand at some distance from each other. Company B can be concluded as the leader over the years and has more powerful models in the 2000s.

The correlation of the defined best-response sets of the players is studied showing a measure of their linear dependence. The p-value values indicate the significance of the results and the relationship between the values. Table I shows the correlation coefficient showing the strength of the relationship between best-response sets of the players. It can be seen that most of the FOMs have the strong relationship, what can also be explained by the high competition in the automobile tradespace. The highest competition is happening in average fuel consumption, the lowest - in car displacement. All p-values are close to 0 corresponding to a significant correlation and relationship in sets.

TABLE I. Correlation of players FOM best-response sets

FOM	Corr	p-value
Average fuel consumption	0.895	2.97e-15
Total max engine power	0.851	1.73e-12
Acceleration	0.852	1.6e-12
Empty mass	0.785	1.24e-09
Max loading capacity	0.701	3.31e-07
Displacement	0.526	4.15e-04
Price	0.815	8.41e-11

The regression analysis is conducted for another estimation of the relationships among the considered players. First, the best-response set of one of the players is considered as a dependent variable from the sets of another player. The use of F-tests includes the study of the hypothesis that a dataset in a regression analysis follows the simpler of two proposed linear models that are nested within each other. Table II provides the regression analysis for the available technology FOMs considering Company A characteristics as the dependent variables; Table III - the regression analysis considering Company B characteristics as the dependent variables.

The resulting p-value is much less than the common levels of α, what means the results are statistically significant. The F-test presents the influence of the FOMs values between the players and the correlation between the variables. The highest results are obtained for Total max engine power, Average fuel consumption, Empty mass, and Price. It shows the higher dependence and competition in such FOMs.

TABLE II. Regression analysis of best-response FOMs for player A

FOM	Coef	SE	F	p-value	T	p-value
Average fuel consumption	0.79	0.0946	69.2	3.58e-10	8.3178	3.58e-10
Total max engine power	0.80	0.0785	104	1.44e-12	10.204	1.44e-12
Acceleration	0.91	0.1183	59.7	2.18e-09	7.7296	2.18e-09
Empty mass	0.81	0.0928	76.8	9.34e-11	8.7641	9.34e-11
Max loading capacity	0.46	0.0874	27.2	6.28e-06	5.2182	6.28e-06
Displacement	0.62	0.1464	17.7	0.000149	4.2012	0.00015
Price	0.57	0.0657	74.3	1.43e-10	8.6217	1.43e-10

TABLE III. Regression analysis of best-response FOMs for player B

FOM	Coef	SE	F	p-value	T	p-value
Average fuel consumption	0.81	0.0976	69.2	3.58e-10	8.3178	3.58e-10
Total max engine power	0.90	0.089	104	1.44e-12	10.204	1.44e-12
Acceleration	0.66	0.0856	59.7	2.18e-09	7.7296	2.18e-09
Empty mass	0.81	0.0928	76.8	9.34e-11	8.7641	9.34e-11
Max loading capacity	0.90	0.1728	27.2	6.28e-06	5.2182	6.28e-06
Displacement	0.50	0.1206	17.7	0.000149	4.2012	0.00015
Price	1.16	0.1342	74.3	1.43e-10	8.6217	1.43e-10

V. CONCLUSIONS

Technology evolution has a critical influence on industries and individual enterprises. To compete successfully, companies apply technology planning and roadmapping frameworks and particular CI and CTI methods for competition investigation. The game-theoretic planning methodology examines a separate technology by the use of two figures of merit and the simulation of technology competition. It is essential to choose the FOMs based on the level of a present competition affecting the outcomes of the game simulation.

The paper proposes a concept of competition-driven FOMs which are more sensitive to the technology competition and strategic moves of the players in the tradespace. This concept is used to support and improve the results of the game-theoretic framework which depends on the level of competition. For this purpose, the approach of visual representation, best-response correlation and regression analysis for the preliminary is suggested.

The automotive market is chosen for the demonstration of the competition influence on the technical evolvement of two firms. It is concluded that there are more sensitive FOMs like total max engine power and average fuel consumption. This process is used to obtain more information to assist technology planning considering evolving technology environment and the rival competitors' development.

The future work will be focused on investigating competition in different technology segments within one technology tradespace, conducting more case studies in other highly-competitive markets using more metrics for determining the technology competition influence.

REFERENCES

[1] M. E. Porter "Technology and Competitive Advantage", Journal of Business Strategy, Vol. 5 Issue: 3, 1985.

[2] K. Smirnova, A. Golkar, R. Vingerhoeds "A game-theoretic framework for concurrent technology roadmap planning using best-response techniques", Proceedings of the 12th Annual IEEE International Systems Conference, pp. 208-214, 2018.

[3] A. M. Ross, D. E. Hastings, "The tradespace exploration paradigm", INCOSE Int. Symp., vol. 15, no. 1, pp. 1706 1718, 2005.

[4] K. D. Weiss; L. G. Almeda, Brinks Gilson & Lione, "Competitive Intelligence Understanding Current Trends in the Patent Landscape for Nanomaterials", 2017.

[5] McKinsey & Co, "How companies respond to competitors: a McKinsey global survey", 2008.

[6] D. J. Teece, "Competition, cooperation, and innovation", Journal of Economic Behavior & Organization, 18(1), pp. 1-25, 1992.

[7] Yu Haidong, Tian Qihua, Zou Ying, "Game analysis with incomplete information and selection of service providers in financial competitive intelligence activity," 2010 International Conference on Computer Design and Applications (ICCDA), vol.2, no., pp.V2-461,V2-465, 2010.

[8] Y. Zhang, D.K.R. Robinson, A.L. Porter, D. Zhu, G. Zhang, Jie Lu, "Technology Roadmapping for competitive technical intelligence", Technol. Forecast. Soc. Change, 2015.

[9] D. Ben Sassi, A. Frini, W. Ben Abdessalem and N. Kraiem, "Competitive intelligence: History, importance, objectives, process and issues", 2015 IEEE 9th International Conference on Research Challenges in Information Science, pp. 486-491, 2015.

[10] I. Anica-Popa and G. Cucui, "A Framework for Enhancing Competitive Intelligence Capabilities using Decision Support System based on Web Mining Techniques", International journal of Computers, Communications and Control, vol. 7, no. 4, pp. 326-334, 2009.

[11] J. J. McGonagle, C. M. Vella, "What is Competitive Intelligence and Why Should You Care About It", in Proactive Intelligence The Successful Executive's Guide to Intelligence, Springer Publishing Co., NY, Chapter 2, pp 1-19, 2012.

[12] S. Alampalli, "Role of CI for Opportunity Assessment", Competitive Intelligence Magazine, vol. 5, no. 4, pp. 21-24, 2002.

[13] W. Zhijin, Wang, Z Han, Z. Peng, "The CTI Strategy of Enterprise in Dynamic and Complex Competitive Environment", Proceedings of International Conference on Technological Innovation, pp. 14-23, 2010.

[14] K. Fishwick, "The Role of Competitive Intelligence in the Global Automotive Supply Chain, in Competitive Intelligence and Global Business, D.L. Blenkhorn, C.S. Fleisher (eds.), Greenwood Publishing Group, Inc., London, pp. 253-269, 2005.

[15] Lu An, Chuanming Yu, "Self-Organising Maps for Competitive Technical Intelligence Analysis", International Journal of Computer Information Systems and Industrial Management Applications, ISSN 2150-7988 Volume 4, pp. 083-091, 2012.

[16] P.K. Dutta, "Strategies and Games: Theory and Practice", MIT Press, 1999.