

What's the Principles of Technology Management—Eliciting Technology Management Principles through Expert Opinion

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Abstract—Literature in technology management says very little about the principles of technology management and they are rarely discussed in the literature. Hence, there is no consensus agreement about these principles. Therefore, there is a need for consultation with TM experts, as the experts in here are referring to the leading scholars (i.e. academic scholar and scholar practitioner) in the area of Technology Management. Therefore, it is believed that the proposed concept and pertinent ideas in this study are expected to be of high value for the researchers and practitioners in exploring the contexts of Technology Management, as this study also reveals what are the key principles in technology management as of today.

Index Terms—Principles, Technology Management and Expert Opinion.

I. INTRODUCTION

The principles of Technology Management (TM) are not clear in literature, as there is no consensus agreement about these principles. Therefore, there is a need for consultation with TM experts, as the experts in here are referring to the leading scholars (i.e. academic scholar and scholar practitioner) in the area of Technology Management. Even the principles of technology management are rarely discussed in the literature, as most of technology management literature is focused on the direction of incorporating technological issues into business thinking, decisions and processes [1]-[3]. Therefore, it is believed that the proposed concept and pertinent ideas in this study are expected to be of high value for the researchers and practitioners in exploring the future context of Technology Management. The researchers have identified about nineteen active scholars (leading scholars and scholar practitioners) in the area, and the question was sent through via electronic mail to them. Six experts (leading scholars in the field) participated, responding to the question submitted, at approximately weekly intervals.

II. METHOD OF STUDY

The principles of Technology Management (TM) are not clear in literature, as there is no consensus agreement about these principles. Therefore, there is a need for consultation with TM experts; a quick opinion survey study has been

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carried out in order to elicit the key principles in the TM area.

To achieve this, the researchers identified the TM scholars based on their publications in the TM area, which reflects their expertise. Then, the researchers sent an e-mail to them with the following question:

- 1) Could you list what you believe to be the three (3) main principles of technology management? The key idea of this question was to invite the scholars to identify what they perceived to be the key principles of TM.

This research approach is consistent with references [4]-[6] who conducted an internet-based survey used to synthesize the opinions of experts on their studies. As such, an expert opinion survey is practical and much cheaper in relation to the other techniques, as well as minimizing time delays. Similarly to the reference [7] also claim that survey is the most common method for soliciting input from groups of experts when face-to-face meetings are impractical. Hence, it is relatively quick, reasonably easy, inexpensive and avoids the negative dynamics of face-to-face meetings [7].

Thus, these techniques are used to address complexity and uncertainty in an area where knowledge is imperfect, where there are no correct answers or hard facts [8]. Further, the similarity is underlined with the concept that a group of experts is better than one expert when exact knowledge is not available [8]. According to reference [8] also put forward their view that participants are stakeholders and/or subject matter 'experts'; selection criteria is pre-determined whereby the findings represent synthesis opinion and not a statistically significant result.

Following on from that, the researchers conducted a face-to-face interview with the founder of International Associate Management of Technology (IAMOT), Prof. Dr. Tarek Khalil during the European Conference on Management of Technology (EUROMOT) at Glasgow. The aim of doing this interview was to validate the early findings from the expert opinion survey.

Table I shows the publication of scholars in TM to justify them as the expert of this field.

III. FINDINGS

Table II summarises the responses from the scholars, which were contacted.

The findings are interesting as they suggest that there are areas with some degree of consistencies and common ground. From the findings of opinion survey and face-to-face interview, which were previously described in Table II together with the TM literature, the following sections

discuss what the key principles of TM might be.

TABLE I: PUBLICATION FROM SEVERAL SCHOLARS

Scholars	Publications
Scholar A	International Journal of Innovation and Technology Management, Journal of R&D Management, Engineering Management Journal, Technovation, Proceedings of the IEEE conference, Proceedings of the Portland International Conference on Management of Engineering and Technology (PICMET), Proceedings of the International Conference on Management of Technology (IAMOT), Journal of Research Technology Management, International Journal of Technology Intelligence and Planning, Technological Forecasting & Social Change, Proceedings of the Institute of Mechanical Engineers, EurOMA Conference, Process Research in Operations Management
Scholar B	International Journal of Innovation and Technology Management, Journal of R&D Management, Engineering Management Journal, Technovation, Proceedings of the R&D Management conference, Proceedings of the IEEE conference, Proceedings of the Portland International Conference on Management of Engineering and Technology (PICMET), Proceedings of the International Conference on Management of Technology (IAMOT), Journal of Research Technology Management, International Journal of Technology Intelligence and Planning, Technological Forecasting & Social Change, Proceedings of the Institute of Mechanical Engineers, Process Research in Operations Management
Scholar C	Journal of Management Decision, International Journal of Management, Journal of Small Business and Enterprise Development, Journal of Business Venturing, International Journal of Manpower, International Journal of Educational Management, Journal of Organizational Behaviour, Handbook of qualitative research methods in entrepreneurship, European Journal of Innovation Management, International Journal of Environmental Research and Public Health, International Journal of Business and Systems Research, International Journal of Performability Engineering
Scholar D	Journal Research Technology Management
Scholar E	Journal of Product Innovation Management, Text book Technological Innovation, International Journal of Operations and Production Management, Journal of Quality Management, Journal of Strategic Finance, Journal of Management Science, Academy of Management Journal, Journal of Operations Management, Annals of Operations Research, Journal of Decision Sciences Book: Managing Innovation, Managing Technological Innovation, Engineered in Japan, Managing the Design-Manufacturing Process, Manufacturing Strategy: The Research Agenda for the Next Decade, Taking Charge of Manufacturing
Scholar F	Journal of Management Decision, International Journal of Technology Management, International Journal of Product Development, International Journal of Product Lifecycle Management, International Journal of Automobile Technology & Management, Book: Technology Management
Tarek Khalil	Book: Management of Technology: The Key to Prosperity in the Third Millennium; Management of Technology: The Key to Competitiveness and Wealth Creation; Civilization, Modern Technology and Sustainable Development Volume I; Civilization, Modern Technology and Sustainable Development, Volume II; Management of Technology, Sustainable Development and Eco-Efficiency; Management of Technology V: Technology Management in a Changing World; Proceedings of International Conference on Management of Technology

Reference [9] claims that technology development requires financial resources, conducive economic conditions, relevant administrative support, organisations which can apply new technology, a suitable physical infrastructure and

a supportive culture. Furthermore in reference [10] suggest that technology development is “a process of simultaneously managing flows of resources and ideas. It involves the replacement of existing technology by one that is more advanced”. In line with this, also claim in [11] that technology development focuses primarily on establishing new functionality and understanding underlying phenomena related to new technologies where technology development bears the promise of making product development more predictable and easier to rationalise. In addition, a new technology development process is in fact a learning process in which new knowledge is created [12] and the importance of technology development has also been addressed by authors such as [13]-[17]. Consistent with this, Scholar A claims that the TM principle can be seen as the evolutionary nature of technological development (S curves etc), while Scholar C insists that clear norms for exploration is the key principle. Further, Khalil suggests that exploration and technology development maybe is one of the principles, as one need to do exploration for new technology.

TABLE II: FINDINGS FROM SEVERAL SCHOLARS

Scholars	Principles of Technology Management
Scholar A	1. The evolutionary nature of technological development (S curves etc). 2. The need to link technology to the market to realise value (as done through innovative products and services and supported by techniques such as roadmapping). 3. Technological know-how as a key resource in an organisation (where technology needs to be identified, selected, acquired, exploited and protected).
Scholar B	1. To incorporate technological issues into business thinking, decisions and processes
Scholar C	1. High employee involvement and motivation. 2. Leadership support. 3. Clear norms for exploration.
Scholar D	1. To develop and exploit the firm's capacity for innovation. 2. To acquire, develop, and allocate an organisation's resources where technology is a resource. 3. Understanding one's innovative capabilities and using those capabilities to leverage business.
Scholar E	1. Sorry, no such principles exist
Scholar F	1. I think that there is a book to be written on such principles and I have no idea who could do the job. Not me for sure.
Tarek Khalil	1. Exploration and technology development maybe is one of the principles, as you need to do exploration for new technology. 2. Technology as a whole can be product or process where the improvement requires knowledge, which encompasses know-how. From know-how, one can make improvements in technology. 3. Technology know-how creates the value.

Based on the above discussion, this suggests that **technology development** is one of the key principles of TM.

Technology improvement can be described in a manner of process of improvement (i.e. intellectual know-how) and the result of improvement (i.e. capability). Accordingly to [18]-[21] note that technology improvement refers to enhance the performance of the technology by using advanced engineering analysis techniques to continuously improve technology capability and reliability. This corresponds with Scholar A who claims that technological know-how is a key resource in an organization (where technology needs to be identified, selected, acquired,

exploited and protected). In line with this, Khalil deems that technology as a whole can be product or process where the improvement requires knowledge, which encompasses know-how. From know-how, one can make improvements in technology. Consistent with this, Scholar D also points out the importance of acquiring, developing, and allocating an organisation's resources where technology is a resource. Further, Scholar D also highlights the need to understand one's innovative capabilities.

Based on these discussions, these reflect that **technology improvement** (i.e. process improvement and result of improvement) is one of the key principles of TM.

Technology leadership is referred to the technological direction specifically in providing leadership in technology areas (i.e. how leadership drives the technology) [22], with the success or failure of the programs rests in part on the role of opinion leaders [23]-[25]. In addition, as noted by [26], leadership is referred to as the process of influencing others towards achieving some kind of desired outcomes where shared leadership enhances people's involvement and motivation to generate ideas and to strive for successful implementation [26]. Concise with this, Scholar C suggests that leadership support is the key element in TM principle.

Based on the above discussion, this suggests that **technology leadership** is one of the key principles of TM.

Technology partnerships/supplier participation reflect the interaction and involvement of supplier participation and partnerships, where in certain circumstances suppliers are partners in forming the alliances and collaborations in order to handle technologies activities/issues amongst themselves (i.e. partners, suppliers and producers). This relationship reflects the extent to which both individuals/firms are committed to the relationships, and that they find it to be productive and worthwhile [27]-[28]. The importance of suppliers/partnerships has been addressed by authors such as [22], [29]-[30].

Further, refer to [31] regard that supplier relationship as one of the most important industrial relationships and the participation of suppliers are categorised in terms of different functional areas, namely product design, timely delivery, raw materials supplied, process design, policy equipment/technology/maintenance, and marketing [32]. As such, problems associated with technological uncertainty can be mitigated by greater information sharing through supplier participation [33]. In line with this, Scholar C further informs that high employee involvement and motivation is the key principle in TM. Therefore, this also suggests that supplier participation/partnerships in a wider context, which includes the participation and involvement of employees, is one of the key principles of TM.

Based on these discussions, this suggests that **technology partnerships/supplier participation** is one of the key principles of TM.

Technology pioneering reflects that technology comes in the form of the pioneers that take the risks to develop and commercialise a new technology to the market, thereby developing the potential to earn profits [34]. Several studies have also discussed the importance of pioneering; to be the forefront as the front-runner or technological breakthroughs [35]-[36] and this relates pioneers to gain market share

advantages and are likely to be the market leaders [31],[37]-[38].

Based on the above discussion, this suggests that **technology pioneering** is one of the key principles of TM principles.

According to [39] show that technology management is actually "*the practice of integrating technology strategy with business strategy in the company. This integration requires the deliberate coordination of the research, production, and service functions with the marketing, finance, and human resource functions of the firm*". In addition, Gaynor further accentuates that managing technology into the business requires that organisations to integrate the technologies of all of the functional departments into the business, as this integration implies bringing things together under the same umbrella [39].

The importance of integration has been addressed by authors such as [40]-[43]. In line with this concept, as noted by [44], "*integration is a making of a whole or entire where the whole to be the result of integration is, in this context, technology management*". As such, this reflects that the area of Technology Management has truly become interdisciplinary which emphasises the need to study how to integrate different disciplines and perspective, and also implies its diversification and integration [45]-[46]. This corresponds with Scholar B who claims that TM needs to incorporate technological issues into business thinking, decisions and processes. Consistent with this, Scholar D insists that understanding one's innovative capabilities and using those capabilities to leverage business is the key principle.

Based on these discussions, this suggests that **technological integration** is one of the key principles of TM.

Technological value reflects that technology as value focuses on providing value creation of technology with regard to different contexts (e.g. economy, society). This makes it possible to tell whether a technology is 'bad or good' or even 'better or worse' than other technologies [45] based on [47]. Khalil also accentuates that technology know-how creates the value. Thus, value creation under rapidly evolving markets underlines the need for innovation, flexibility, and speed, pressure for new applications, unique solutions [48]-[50]. Additionally, [51]-[52] suggests that "*value creation in technology firms is largely based on their ability to innovate, that is the ability to assimilate and exploit new knowledge*". In line with this, Scholar A states that there is the need to link technology to the market to realise value, as done through innovative products and services and supported by techniques such as roadmapping. Consistent with this, Scholar D points out that to develop and exploit the firm's capacity for innovation is the key principle of TM.

Based on the above discussion, this suggests that **technological value** is one of the key principles of TM principles.

Technology standards are associated with reducing uncertainty by controlling variety; enhancing competition by clearly defining what is required to serve a market (information); constituting markets by defining the relevant aspects of products [53]-[54], which are accepted and shared within a community [55]-[56].

The importance of standard, further has been discussed by

authors such as [57]-[59] from the issues of product and industrial standards to closed and open standard [60]-[62]. Accordingly to reference [58] suggests that “the ability to establish the innovator’s own technology as standard provides a route to competitive advantage. This is because standards can help create network externality effect through compatibility. Also, standards help tie in the customers since standards allow the creation of a base of compatible users, making it difficult for any competitors to capture on an individual or niche basis”. To a certain extent, standardisation of a system adds value by making systems interchangeable. As a consequence, the competitive basis shifts to performance and functionality.

Based on the above discussion, it is fair to say that **technology standards** are one of the key principles of TM.

Based on the previous discussion, the researchers conclude that there are **eight key principles of Technology Management**, which are:

- 1) Technology Development
- 2) Technology Improvement
- 3) Technology Leadership
- 4) Technology Partnerships/Supplier Participation
- 5) Technology Pioneering
- 6) Technological Integration
- 7) Technological Value
- 8) Technology Standards

IV. CONCLUSION

TABLE III: KEY CONCEPT FROM SEVERAL AUTHORS

TM Identified	Principles	Descriptions	References
Technology Development		Involves the replacement of existing technology by one that is more advanced by establishing new functionality and understanding underlying phenomena related to new technologies.	Herps, et al., [14]; Hoecht[15]; Magnusson and Johansson [11]; Mahmood and Rufin[10]; Ofari[9]; Manaikkamakl[12]; Scholar A; Scholar C and Tarek Khalil
Technology Improvement		Enhancing the performance of the particular technology by continuously improving technology capability and reliability (i.e. process improvement and result of improvement – the end result).	Gehani[34]; Thomas, et al., [19]; Scholar A; Scholar D and Tarek Khalil
Technology Leadership		The technological direction specifically in providing leadership in technology areas (i.e. how leadership drives the technology).	Babcock and Morse [22]; Rogers [23]; Jong and Hartog[26] and Scholar C
Technology		The interaction and	Babcock and Morse [22];

Partnerships/ Supplier Participation	involvement of suppliers in forming the alliances and collaborations in order to handle technology activities/issues amongst themselves (i.e. partners, suppliers and producers).	Carr, et al., [29]; Karandikar and Nidamarthi[33]; Li and Vanhaverbeke[31]; Machado and Manus [30]; Giannakis[27]; Kayis and Kara [32] and Scholar C
Technology Pioneering	Pioneer that takes the risks to develop and commercialise a new technology to the market, and this allows pioneers to gain market share advantages, thereby developing the potential to earn profits.	Ali [35]; Benedetto and Song [38]; Garrett, et al., [37]; Gehani [34]; Li and Vanhaverbeke[31]; Voss [63]
Technological Integration	Emphasises the need to integrate different disciplines and perspectives, and also implies its diversification and integration (i.e. incorporating technology, enterprise business and strategy).	Drejer[45]; Drejer[44]; Capuano, et al., [41]; Christensen, et al., [46]; Scholar B and Scholar D
Technological Value	Focuses on providing value creation of technology with regard to different contexts (e.g. economy, society). This makes it possible to tell whether a technology is ‘bad or good’ or even ‘better or worse’ than other technologies. Thus, value creation under rapidly evolving markets underlines the need for innovation, flexibility, and speed, pressure for new applications, unique solutions.	Drejer[45] based on Maack; Laitinen[51]; Pralahad and Krishnan [48]; Scholar A; Scholar D and Tarek Khalil
Technology Standards	Associated with reducing uncertainty by controlling variety; enhancing competition by clearly defining what is required to serve a market (information); and defining the relevant aspects of products, which are accepted and shared within a community.	Tirole[53]; Baldwin and Woodard [60]; Chituc and Azevedo[56]; Crargil[55]; David [57]; Eisenmann, et al., [61]; Iansiti[62]; Iversen, et al., [54]; Wonglimpiyarat[58]

Table III Identifies the key technology management

principles together with the references that led the researchers to the text descriptions.

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