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TECHNOLOGY MANAGEMENT AS A PROFESSION AND THE CHALLENGES AHEAD

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Abstract:

This paper is aimed at current and future managers in the field of technology management (TM), and those who train and educate them. After briefly describing TM as a management discipline, the potential challenges likely to rise in the field are introduced according to three processes given in the TM framework: innovation, operation and strategy. Then, a set of propositions are developed regarding the potential impact of those challenges on TM professionals. Concentrating on a long term perspective provides TM professionals with the opportunity to consider their existing knowledge and skill base so that they can prepare for the challenges they will face in the future. The paper ends with implications for professionals and educators.

Keywords: technology management, profession, career, technology manager, education, skills

1. INTRODUCTION

This paper aims to understand the challenges facing managers who are pursuing a career in the field of technology management (TM). The discipline of TM dates back to the mid 1950s (Allen, 2004), becoming an established discipline in the late 1980s (Cetindamar et al., 2009). In the 21st century, TM has become a 'traditional business subject', according to the International Association to Advance Collegiate Schools of Business (AACSB, 2009).

The literature describes the intellectual development of TM as a field, and the trends in influential journals that publish papers on TM (Linton and Thongpapanl, 2004; Thongpapanl, 2012; Cetindamar et al., 2009; Duan, 2011). The core focus of TM has changed significantly over the past decades; from research and development (R&D) to strategic management, and ultimately to innovation management (Drejer, 1997; Horwitch and Stohr, 2012).

However, the literature is rather limited when it comes to publications about the profession itself and the people who are responsible for the management of technology. A review of 10 TM-oriented journals (Thongpapanl, 2012) that are published since 2000 shows the limited coverage of the TM profession and education. As shown in Appendix, these TM journals altogether have published about 40 publications on the topics of TM 'education', 'career', 'profession', 'manager', and 'Chief Technology Officer' (CTO). Perhaps not surprisingly, the practitioner-oriented Research-Technology Management journal is prominent, with nine publications related to these topics. In fact, this journal devoted a special issue to the topic of the CTO (May–June 2011). The remaining journals have published one or two individual papers on general TM education and managerial issues.

In recent years, a few papers on TM education have been published (Badawy, 2009; Berg et al., 2015; Horwitch and Stohr, 2012; Labini and Zinovyeva, 2011; Van Wyk and Gaynor, 2014; Yanez et al., 2010) and CTO/technology managers (Deevi, 2011; Smith, 2003, 2007 and 2011; Chipulu et al., 2013; Van der Hoven et al. 2012). The general management literature does not offer much help, either (Herstaat et al., 2007). However, there are few exceptions. For example, the Academy of Management Learning & Education journal published a special issue in 2009 on ‘educating professionals for careers in innovation’, where several papers discussed TM education specifically (Clarysse et al., 2009; Austin et al., 2009). There are also a few other journals such as Management Science that published works directly related to TM professions. However, this paper limits its focus to those studies published in academic journals in the field of TM alone due to our focus on understanding the TM profession from the TM discipline.

The gap in literature on the TM profession inspired the research described in this paper, to explore the challenges facing managers pursuing a career in the field of TM. In fact, this problem also applies to the business profession in general, despite it being based on a well-established and broad management discipline as discussed by Schoemaker (2008). Recently, a similar study has been undertaken to identify changing competence needs of engineers in New Zealand without particular emphasis on education (Pons, 2015). Another paper relates to project managers (Chipulu et al., 2013) and one to supply chain professionals (Prajogo and Sohal, 2013). So, we propose that the TM field should start considering the professional concerns as a theme for research. This is necessary in order to develop as a unifying professional identity as Schoemaker (2008) clearly highlights. As a humble start, this paper addresses the gap in two steps. Firstly, TM as a management discipline as it stands today will be introduced, in terms of the field and the profession. Secondly, and more importantly, the future challenges for the field and its professionals are identified. By doing so, we hope TM professionals could consider their existing knowledge and skill base and make plans to prepare for the challenges they might face in the near future. Similarly, academicians and educators should begin revising the educational programs designed for TM professions. The paper concludes with few suggestions for TM professionals and educators.

2. TECHNOLOGY MANGEMENT AS A PROFESSION

2.1 TECHNOLOGY MANAGEMENT

Due to the complex nature of firms and industries, it is difficult to describe where exactly firms exercise TM activities. Thus, TM framework of Phaal et al. (2004) considers technology as a resource and it emphasizes the dynamic nature of the knowledge flows that must occur between the commercial and technological functions in a firm. In the TM framework, all TM activities are typically linked to or embedded within the three core business processes: innovation, operational processes, and strategy (Phaal et al., 2004).

Considering TM as a dynamic capability (Teece et al., 1997), TM consists of planning, directing, controlling and coordinating the development and implementation of technological capabilities in order to shape and accomplish the strategic and operational objectives of an organization (Cetindamar et al., 2009). Technological capabilities are a collection of routines/activities in order to improve or develop products, processes and existing technology, as well as generating new knowledge and skills (Jin and Zedwitz, 2008).

Even though TM is a distinct management discipline concerned with developing and exploiting technological capabilities that are changing continually, the general area of innovation management and the more specific issues associated with the management of technology and R&D are often confused (Zabala-Iturriagagoitia, 2014). A close examination of the changes in the TM discipline during the period of 1996–2008 shows that innovation has become the leading topic in TM (Cetindamar et al., 2009). For example, a study that examined papers published in the journal of Technovation identified two major themes (Nambisan and Wilemon, 2003): technological innovation and TM. The former theme covers 84% of the journal's articles and deals with issues related to the technology innovation process and policies. The second theme, TM, takes the form of organizational structures intended to facilitate innovation. However, the dominance of one topic starts to misrepresent the TM field, resulting in confusion about the boundaries between innovation and TM. In order to understand what technology managers actually do, it is necessary to resolve this confusion.

Innovation management covers all managerial tasks related to all sorts of innovations. TM, on the other hand, is interested in technology innovations in addition to other technology-related managerial concerns that have little to do with innovation (Cetindamar et al., 2016). Thus, a solution that clarifies the boundaries between TM and innovation management is to use the following rule-of-thumb: TM and innovation management overlap only when an innovation is based on technology. For example, the development of a new television (TV) display technology involves a technology-based product innovation, so there is an overlap, while the development of a new sales channel for a TV is a marketing innovation, whereas the acquisition of a process technology to produce the TV display is related to TM. When it comes to services, the same rule applies. For example, Walk-in clinics accept patients on an ad-hoc basis and with no appointment required. They are innovative health care providers, but their innovation is not based on a technology. Some services are available only through technological innovations. For example, the banking sector offers Automatic Teller Machine (ATM) services that use technological hardware and specific software applications, and are thus an example of a technological innovation.

In addition, a specific innovation might fall into more than one innovation type, making TM and innovation management overlap. For example, the Airbnb Company offers a technology based innovation in the hospitality business, but it includes innovations in marketing, organization, processes and products. Established in 2008, Airbnb became one of the world's largest providers of accommodation in 2014, comparable in scale to Hilton Worldwide. However, it does not own a single hotel since it enables subscribers to rent out their spare rooms or vacant homes to strangers over its Internet platform. Airbnb surpassed 10 million transactions on its platform in 2014, doubling its listings to 550,000 in 192 countries. The company successfully used technologies and developed a new business model with unique marketing and payment methods, radically transforming the idea of hotel accommodation.

TM is not only concerned with managing technological innovations, but also six specific activities/capabilities which technology managers exercise in their daily work (Cetindamar et al., 2016, pp.8-9):

1) *"Acquisition* is concerned with how the company obtains the technologies valuable for its business, based on the buy–collaborate–make decision. In other words, technologies might be developed internally, through some form of collaboration, or acquired from external developers, with management issues depending on the mode of acquisition.
2) *Exploitation* entails commercialization, with the expected benefits needing to be realized through effective implementation, absorption and operation of the technology within the

firm. Technologies are assimilated through technology transfer, either from R&D to manufacturing or from external partners to the internal manufacturing department. Exploitation activities include incremental developments, process improvements and marketing.

3) *Identification* of technology is necessary at all stages of the development and market life cycle. This process must consider market changes as well as technological developments. Identification includes search, auditing, data collection and intelligence processes for technologies and markets.
4) *Learning* is a critical part of technological competency; it involves reflecting on technology projects and processes carried out within or outside the firm. There is a strong link between this process and the broader field of knowledge management.
5) *Protection* includes formal processes such as patenting and staff retention, and needs to be addressed in order to protect intellectual assets within a firm, including the knowledge and expertise embedded in products and manufacturing systems.
6) *Selection* takes account of company-level strategic issues, which requires a good grasp of strategic objectives and priorities developed at the business strategy level. The selection process then aligns technology-related decisions with business strategy."

2.2 PROFESSIONS IN TECHNOLOGY MANAGEMENT

A recent study shows doubling of the size of the executive team, namely the number of positions reporting directly to the CEO during from the mid-1980s to mid-2000s, with approximately three-quarters of the increase attributed to functional managers rather than general managers (Guadalupe et al, 2012). Another study (Menz, 2012) lists a wide range of functional top management team members observable in practice: Chief Technology Officer (CTO), Chief Financial Officer (CFO), Chief Human Resources Officer (CHRO), Chief Marketing Officer (CMO) and Chief Information Officer (CIO). Menz (2012) further highlights that for the specific function of research and development, CTO title is not the only title used, identifying the occurrence of various titles such as Chief Innovation Officer, Chief Medical Officer, and Chief Science Officer associated with this function among Standards & Poor companies. Another study identifies a range of different titles used for corporate executives responsible and accountable for their firm's TM practices: Technical Director, Technology Director, Chief Scientist, Vice President of R&D, and Innovation Director (Tobias, 2000; Van der Hoven et al, 2012).

Overall, although a top managerial position for TM has various titles, these professionals fulfill some common specific roles. Individual managers develop their technological capabilities to various degrees and utilize them when it comes to exercising their board-level roles. Even though not all companies have a position for a senior manager in the top management team, it has been shown in a few available empirical works that having managers responsible for TM make a difference to firm performance (Cetindamar and Pala, 2011; Hartley, 2011). In particular, a survey of 49 electronic and machinery firms in Turkey found that even though the CTO position does not prevail, the roles identified in the literature for those top technology managers are actually performed in varying degrees and most importantly the realization of these roles had positive impact on company performance (Cetindamar and Pala, 2011).

Regardless of the title of a position for technology managers at the company, there is a demand for technology managers and the expected duties from them are increasing due to three main reasons (Berg et al., 2015):

1) The formation and growth of new technology-based firms, as well as the development and implementation of new technologies in large companies (and 'corporate entrepreneurship'), contribute to increased demand for professionals who can understand and function as technology managers (Salomo et al., 2008). Many professions might also need to expand their skills to understand TM so that they can practice their own professions such as university technology transfer / licensing officers, scientists and engineers, corporate executives, and independent entrepreneurs (Mom et al., 2012).
2) Even though it is recognized that TM is mainly a profession for companies developing technologies and manufacturing companies that are utilizing technologies, the impact of technology is pervasive across all sectors, and technology managers are needed by companies that are not technology-based or manufacturing focused (Chang et al., 2014). It is important to remind that many economies are based on services such as the US where around 70% of the US economy is in the service sector (Berg et al., 2015). Given the dynamic nature

of how technology evolves, Badawy (2009) describes in detail the pervasiveness of the diffusion of technologies across many services in sectors such as healthcare, telecommunications, banking, and media.

3) Besides companies, technology managers are in demand by government organizations/institutions (Horwitch and Stohr, 2012). The increase in the rate of public and private investment in technology has manifested itself in numerous technology-based economic development and technology transfer initiatives at regional, state and national levels. This development results in the rise of collaborative research and commercialization that demands more technology managers.

TM education rests on knowledge developed over many years (Van Wyk and Gaynor, 2014; Yanez et al., 2010) that covers the comprehensive body of knowledge for TM in four groups: 1) knowledge of technology; 2) knowledge of technology-linked management topics; 3) knowledge of general management topics; and 4) knowledge of supporting disciplines. TM education is mainly lies on this body of knowledge. Since technologies and markets are highly dynamic, the radical changes are ongoing in core business processes, namely innovation, operational processes and strategy. The expected changes on the basis of each business process will be outlined in Section 3, accompanied with a set of propositions that will show the likely impact of these changes on TM capabilities and skills.

3. CHALLENGES AHEAD

3.1 INNOVATION

The recent literature highlights changes in innovation types and transformations in innovation processes (Horwitch and Stohr, 2012; Berg et al. 2015; Phan et al., 2009). Both developments seem to pose challenges to TM professionals.

Innovation types

Innovation literature offers many innovation types, characterized in various ways according to purpose and context (Utterback and Abernathy, 1975; Bower and Christensen, 1995; Tidd and Bessant, 2013). The Oslo Manual (OECD, 2005) attempts to simply the list under four general innovation types: product, process, marketing and organizational. However, recently, new types of innovations have become noteworthy in terms of their relevance to technology managers, such as: eco-innovation, reverse innovation, social innovation, and design-driven innovation:

- Eco-innovation is described by the European INNOVA panel (Schiederig et al., 2012) as the creation of products, services, and processes that can satisfy human needs and bring quality of life to all people with minimal use of natural resources per unit output, and a minimal release of toxic substances.
- Reverse innovation refers to product and service innovations aimed at resource-constrained customers in emerging markets (Zeschyk et al., 2014).
- Social innovation meets societal needs ranging from working conditions and education to community development and health (Horwitch and Stohr, 2012).
- Design-driven innovation is based on user experience and meaning for products and services. It offers surprise and pleasure at the look and feel of a product or a service (Tidd and Bessant, 2013).

These four major innovations will have an impact on TM and its profession by widening the applications of technology into new areas such as social problems, as well as the participation of new actors in the process of technological innovation. New innovations based on technologies are diffusing into many application areas in numerous ways. Thanks to these types of innovations, TM will become more focused on social and environmental problems, which will be further discussed below. An example is the rise of the crowdfunding sector where firms such as Kiva facilitate a virtual fund raising activity for entrepreneurs living in developing countries over the Internet. Another example is the Aravind Eye Hospital that was established in India in 1976 as a social enterprise. The founder, Dr. Venkataswamy, introduced a new business model where each paying customer paid for their cataract operations as well as for two non-paying customers. Procedures and systems are standardized to increase scale and reduce costs, and offering a high quality service enabled by a number of integrated innovations in the company. By doing so, Aravind Eye Hospital has managed to treat more than four million customers since its establishment.

Product and service innovations aimed at resource-constrained customers in emerging markets highlight the reality that innovation and TM need to apply across cultures and geographies. Innovations originating in or directed to emerging markets typically result in products that may seem inferior compared with advanced technologies, in that they may not offer as wide a range of features or as high a level of technical performance, or they may be smaller or made of less expensive materials (Hang et al., 2010). However, these products are characterized by other features, such as low cost, small size or simplicity of use, and so may out-compete advanced technologies in these market contexts. Companies looking to develop these innovations need to be sensitive to the local context.

A recent study (Zeschyk et al., 2014) goes further and distinguishes between types of resource-constrained innovations on the basis of novelty of solution and typical traits. At the one end is reverse innovation, where the novelty of the solution ranges from low to medium, the solution is a cost/value/application-engineered global one with traits such as cost-effective raw materials, local sourcing and new applications (e.g. portability). An example of reverse innovation is the Logiq book produced by General Electric, a portable ultrasound device that was initially produced for emerging markets but later diffused into advanced countries. At the other extreme is cost innovation, where the novelty of solution is low, offering a cost-engineered emerging market solution with traits such as cost-effective raw materials, local sourcing and smaller package sizes. An example of cost innovation is the Chinese firm Huawei which produces smart phones at about 20% of the cost of established competitors.

Innovativeness in developing countries is not limited to manufacturing. A study has shown the important role played by developing economies in the origin and types of innovations in financial services that are offered via mobile phones (Van der Boor, 2014). The findings indicate that 85% of the innovations in this field have originated in developing countries and at least 50% of all mobile financial services were pioneered by users, approximately 45% by producers, and the remaining jointly developed by users and producers. The findings also highlight that the main factors contributing to these innovations occurring in developing countries are the high levels of need, and the existence of flexible platforms, in combination with increased access to information and communication technologies. Additionally, services developed by users have diffused at more than double the rate of producer-innovations. Finally, the study observed that three-quarters of the innovations that originated in non-OECD countries have already diffused to OECD countries.

The findings call for a re-examination of new sources of innovation and suggest that technology managers need to be ready to collaborate across countries and cultures (Phan et al., 2009). Thus, we suggest that:

> Proposition 1: The rise of new innovation types and new innovation players will increase the development of interdisciplinary skills and team-learning.

Innovation Process

In 2013, as part of its 75th anniversary celebration, the Industrial Research Institute (IRI) commissioned a project to consider the shape of R&D looking forward 25 years, to explore how the trends of today might affect research and TM in 2038 (Farrington and Crews, 2013). The study described detailed sets of scenarios, one of which is summarized here to provide an insight into what the future might look like in 2038 from a technology manager's perspective.

The scenario is called 'Three roads to innovation' and considers three new paths toward innovation: Hollywood R&D, Communities of Brains, and Innovation Tribes. According to the first path, many corporations will work as a small production companies that pull together freelance talent on a project-by-project basis. The second path underlines the network of individuals directly connecting their capabilities to communities in order to solve social problems and develop transformational science. The third path foresees the formation of insular communities like tribes that could work together but protect themselves by obtaining their intellectual property.

Based on this scenario, the study lists four implications for research and TM (Farrington and Crews, 2013, pp.25-26):

1) *"R&D Value Proposition:* R&D will not only identify future customer needs but also pick the best research model to solve these needs. Companies will value speed-to-market and strong evidence of demand. The use of fast prototyping and user feedback will mean projects get market exposure and feedback before being handed over to formal marketing and sales systems.
2) *Talent Management*: There will be an increasing reliance on freelance talent, so managers will need to spend a lot of time building a community of talent. They will form teams quickly by using their community. Simulations will help increase the speed and accuracy in assembling the right team. As software systems are developed for talent and project management, researchers will need to develop an ability to manage or be managed by artificial intelligence or expert systems. This will include the need to maximize human creativity in a world of automation.
3) *Portfolio Management*: The ability to articulate exactly what the company is looking for is critical in managing the portfolio. Managers will handle many different types of projects, from highly open crowd-sourced models to tightly controlled internal programs. Managing the flow of information for each project to maximize creativity and to protect trade secrets will be a key source of advantage.
4) *Project Management*: Stage-Gate systems will not disappear, but will be automated and the number of gates will be reduced by using simulations and mapping project progress. Managers will concentrate on being more collaborative and integrated with the rest of the organization or community, rather than on daily project management. This complex task will be possible thanks to the use of intelligent software. Assembling and managing team capabilities will become a critical management skill."

In short, TM professionals need to be aware that a paradigm shift is taking place in innovation, which is being democratized with active user roles and open innovation processes (Chesbrough and Brunswicker, 2014). As Von Hippel (2005) describes it as democratization of innovation, open innovation already account up to 10-40% of products developed or modified by users.

Further, the scope is widening from product and service innovation to business model and societal innovation (Horwitch and Stohr, 2012; Groen and Walsh, 2013). Different stakeholders are involved from the public sector, companies, academia, NGOs, citizens and users. Information and communication technology is a key enabler for mobilizing and aggregating 'collective intelligence and creativity' (Green, 2007). An example and expression of this shift in innovation can be seen in the launch of the European Network of Living Labs in 2006. The labs bring together users and experts to foster collaborative innovation and are a step towards a European Innovation System based on open co-creative labs for global competitiveness.

Although future scenarios might be very different, managers should begin to build relevant organizational competencies as the global market for R&D and innovation processes change (Thomke and Manzi, 2014). In sum, we propose that:

> Preposition 2: Technology managers will increasingly require creativity and talent management, new marketing and product development techniques such as ethnography and rapid prototyping in order to tackle with open innovation environments where many stakeholders exist.

3.2 OPERATIONAL PROCESS

Due to the interdisciplinary nature of technological advancement and TM as a social science, various academic and practical perspectives need to be integrated in a coherent manner. Recent developments are adding new complexity for TM professionals, and two key areas are particularly important: sustainability and the integration of services with products (Apreda et al., 2014; Berghman et al., 2012; Parida et al., 2014; Porter and Heppelmann, 2014; Seebode et al., 2012; Schiederig et al., 2012; Tidd and Bessant, 2013).

Sustainability

The World Wide Fund for Nature suggests that lifestyles in the developed world at present require the resources of around two planets (WWF, 2010). According to the NaturalEdge Project, the next waves of innovation will be driven by simultaneously improving productivity and protecting the environment. As shown in Figure 1, technological innovations and design know-how have the potential to tackle many environmental problems cost effectively and profitably. For example, 'green' buildings, hybrid cars, transport systems, and a wide array of recycling and other enabling technologies will have a major impact on the future sustainability of business and society. In addition, sustainable global economic growth is not possible without a portfolio of sustainable energy sources enabled by renewable technologies.

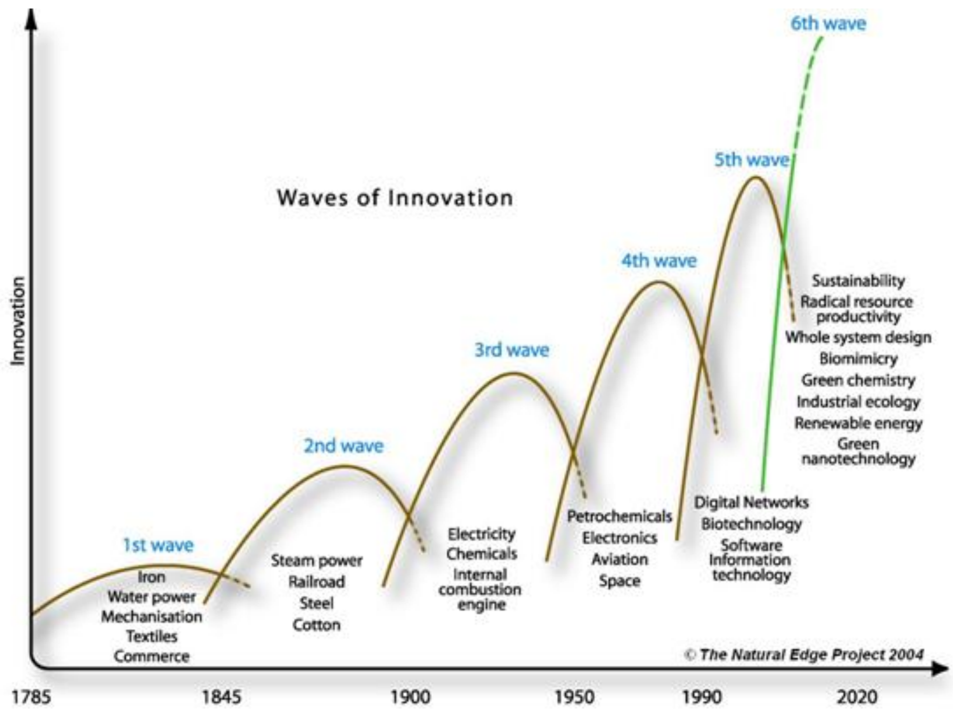

Figure 1 Waves of Innovation

Source: http://www.naturaledgeproject.net/Keynote.aspx licenced under http://creativecommons.org/licenses/by/3.0/

Sustainability is not only about technology; it also requires sustainable products, processes, and systems, particularly sustainable supply chains. The entire supply chain should be designed and managed from a total life-cycle perspective, considering coordination between product, process, and supply chain design. Only then will it become possible to efficiently reduce environmental and societal impacts of production and consumption while maintaining profitability. An example is Philips, a Dutch multinational consumer products company (Seebode et al., 2012). In 2003, a structured sustainable supply chain program was introduced and the Philips Environmental Report (first published in 1999) was extended into a Sustainability Report. In 2009, the Philips Annual Report covered all aspects of sustainability in Philips' business practices that focus on reducing the environmental and ecological 'footprint' of all Philips products. Since 2004, Philips has defined 'green' products as those offering significant environmental improvements in one or more key focal areas such as energy efficiency, hazardous substances, recycling and disposal, and lifetime reliability. The lifecycle approach is used to determine a product's overall environmental impact over its total life cycle.

Another good example of sustainability is Nike, which was ranked as the 7th most innovative firm in 2014 according to the Fast Company (2014) because of its 'Making' approach that helps companies measure the environmental impact of using different materials. Hannah Jones, Nike's VP of sustainable business and innovation, has described how Nike created a large database of materials for the entire industry. Nike plans to eliminate the use of hazardous chemicals in the creation of its products by 2020 and the approach has been incorporated into the curriculum of two design schools and applied in 23 countries. The company also expanded its ambitious 'Launch' program, which it created in collaboration with NASA and the US State Department. Hundreds of key players in the materials ecosystem come together to discover, incubate, and accelerate companies developing innovative materials to be used on a wide scale to address global issues. She argues that sustainability cannot be considered just for a single product line; it has to be considered in everything a company does.

Coordinating product and supply chain design decisions will play a critical role in improving performance across supply chains (Bevilacqua et al., 2007; Berghman et al., 2012). Product design determines future costs, which in turn depend on supply chain configuration, such as the number and location of suppliers, their capabilities and capacities. By integrating sustainability into supply chain, the potential environmental impact throughout the life cycle of the product could prevent or reduce as much as possible the emission of harmful substances, excessive use of energy or nonrenewable energy sources. That is why sustainability is a key element discussed by supply chain professionals (Prajogo and Sohal, 2013). Coordinating sustainable product and supply chain design decisions requires consideration of all product life-cycle stages within the supply chain and effective use of technologies. In turn, we suggest:

> Proposition 3: Environment concerns coupled with increased opportunities through clean technologies result in higher expectations from technology managers to have capabilities in managing sustainability across the supply chain.

Integration of services with products

The service sector has become a key application domain for engineering and TM, since it represents 60-70% of Gross Domestic Product in developed economies (Berg et al., 2015). As Tidd and Bessant (2013) describe, many examples of technological innovation can be found in services. Clearly, information technologies have transformed many service industries, including banking, insurance, healthcare and education. That is why it is no surprise to find out that the world's first business computer was used in a service-intensive company, namely to support bakery planning and logistics for the UK catering services company J. Lyons and Company (Tidd and Bessant, 2013).

Besides service industries, manufacturing companies are becoming product-service providers. Increasingly, manufacturers sell the benefits from the use of a product rather than just the product itself, as explained by the case of the passenger train manufacturer Alstom Transport (Euchner, 2014). The main rail route between London and Glasgow utilizes high-speed electric trains manufactured by Alstom. The trains are operated by Virgin but they are maintained by Alstom. In addition to its role as a manufacturer, Alstom maintains the performance, availability and reliability of the trains so that Virgin can focus on serving passengers. Virgin assesses the performance of Alstom using metrics that relate to its own business process, such as any disruption experienced by passengers. Alstom then arranges its operations to perform against such metrics.

The integration of products and services is further strengthened with two developments: the widespread application of sensors and the rise of design-driven innovations (Porter and Heppelman, 2014). The former enables gathering and using of extensive information on products and services. A McKinsey Quarterly article on the topic describes how the proliferation of sensors is making possible a new level of automation in data collection, transmission and analysis (Chui et al., 2010). When products are embedded with sensors, companies can track the movement and performance of products and monitor interactions with them. Business models can be fine-tuned to take advantage of this behavioral data. For example, when sensors and network connections are embedded in a rental car, it can be leased for short time spans to registered members of a car service, rental centers become unnecessary, and each car's use can be optimized for higher revenues. Zipcar has pioneered this model, and more established car rental companies are starting to follow.

Similar to the profound impact of sensor technologies, design-driven innovation as a new managerial approach offers many advantages. Technologies coupled with design further help both service and manufacturing firms to change the meaning of their offerings to customers. As Verganti (2009) proposes, people do not buy products but they buy 'meanings', because people use things for profound emotional, psychological and socio-cultural reasons as well as utilitarian ones. Design-driven innovation becomes a new dimension for companies to compete on. For example, the Nintendo Wii changed the meaning of computer gaming from a largely individual activity to an interactive family one. Nintendo used new sensor technology as well as design features that resulted in a unique look and feel. In short, companies might bring various innovations together than can have a radical impact in markets by integrating design- and technology-driven innovations together.

The impact of design-driven innovation is profound, particularly for services. For example, restaurants move from an emphasis on food towards experience innovation, where restaurants are systems of consumption involving the product, its delivery, and the physical and cultural context (Tidd and Bessant, 2013). Service providers such as airlines, hotels and entertainment businesses are differentiating themselves with such experience innovations.

Whatever form the transformation associated with the integration of products and services takes, it is clear that technology managers will need to understand the dynamics of manufacturing and service industries, and they need to be ready to create new business models, improve business processes, and reduce costs and risks through the extensive data they will gather on products and services. Thus, a different set of capabilities are needed to succeed in the integration of product-services, including business model design, partner network management, and service delivery network management (Chang et al., 2014). Companies need to find ways to develop these key capabilities in their own organizations in order to protect their long-term market competitiveness. So, we conclude that:

> Proposition 4: In a globally dispersed open source world, in which users, individuals, groups or communities are the creators of modern innovative products and services, technology managers will increasingly need to excel in cross-disciplinary communication, multidisciplinary team management, and service management.

3.3 STRATEGY

New Business Models

Innovations change all aspects of business, including strategies. Utterback (1995) has clearly shown that attackers from the outside have an advantage when a new business model threatens an existing market or technological regime. The recent radical innovations are based on digital technologies and they drive 'digitalization': an emerging business model that includes the extension and support of electronic channels, content and transactions (Porter and Heppelman, 2014). Brynjolfsson and McAffee (2014) draw an analogy to the industrial revolution which implicitly suggests that the digital revolution will be comparable in its effects on long-run economic growth. With the digitization of 'just about everything' come streams of data making possible a ubiquitous 'Internet of things' and providing the necessary information for continuing improvement and new discoveries about complex processes (Chui et. al., 2010; Iansiti and Lakhani, 2014).

Digitalization is much more than technologies, with new collaborative ways of doing business with a wide variety of partners. A good example is the story of Nest, a company producing the digital thermostat and smoke detector that was acquired by Google in 2014 for $3.2 billion (Iansiti and Lakhani, 2014). The Nest thermostat creates value by digitizing the entire home-temperature-control process from fuel purchase to temperature setting to powering the heating, ventilation and air-conditioning system. This company is based on a new business model since the revenue is not based only on its direct service: temperature measurement and smoke detection. Nest can make money from electric utilities on the basis of outcomes: Google can aggregate data on energy consumption patterns and offer the utilities a service in return for a percentage of their savings; in addition it can pass some of those savings back to consumers. Another partner of Nest is Jawbone, a company that produces wearable technology. Its products detect when someone has awakened and then dynamically adjust the home temperature by communicating with Nest. There are all sorts of possibilities to connect digital data collected by Nest and its potential partners. The example of Nest is illustrative of what smart products might offer in the future and the challenges they pose for technology managers in terms of business models and collaborations.

Besides new business models, digitalization also emphasizes big data and its use in new ways for organizing business. McKinsey Global report (2010) shows that nearly 12 terabytes are created each day in tweets alone and there are many more data from social media streams, digital images, banking and transaction records, sensors, and other sources. And the flow is accelerating; 90% of the data in the world today was created in the last two years and there will be 44 times more of it by the year 2020 (Chui et al., 2010). The proliferation of data brings complexities in business relationships and requires building an analytical capability for organization (Davenport et al., 2001). The digital revolution in design and manufacturing such as the rise of 3D printing, also called additive manufacturing, is further blurring the roles of supply chain actors (Petrick et al., 2014). An interesting example is Shapeways (www.shapeways.com) that enables individuals to design, prototype, and buy or sell products online. At Shapeways, individuals can download a product design and then customize it, reload it to the Shapeways website, and have it produced by the company’s 3D printers. Shapeways then ships the finished product to the customer. Thus, we conclude that:

> Proposition 5: The increase in digitalization increases the need for technology managers’ skills for data analytics and new business model development.

Besides digital technologies, many emerging technologies such as nanotechnology and biomaterials are bringing new opportunities, however, there is a lack of strategic approach to these technologies where all aspects of commercial, policy, environmental, ethical and societal implications are taken into consideration (Groen and Walsh, 2013). In particular, a study on a specific type of TM professional, technology transfer professionals (Mom et al., 2012), highlight the need for skills in the commercialization of new and emerging technologies by technology managers.

Entrepreneurship skills and knowledge help technology managers for managing emerging technologies and their commercialization. In addition entrepreneurial skills help managing the complex environment where entrepreneurship flourishes: ambidextrous organizations that balances exploration and exploitation activities (Derbyshire, 2014; Thomke and Manzi, 2014; Tushman, 2014). Exploration includes things captured by terms such as search, variation, risk taking, experimentation, play, flexibility, discovery, innovation. Exploitation includes such things as refinement, choice, production, efficiency, selection, implementation, execution. Adaptive systems that engage in exploration to the exclusion of exploitation are likely to find that they suffer the costs of experimentation without gaining many of its benefits. They exhibit too many undeveloped new ideas and too little distinctive competence, while systems that engage in exploitation to the exclusion of exploration are likely to find themselves trapped below optimal equilibrium. As a result, maintaining an appropriate balance between exploration and exploitation is a primary factor in system survival and prosperity.

When markets become more dynamic, uncertain and multicultural, senior management teams feel the pressure to grasp the cognitive complexity and make the tradeoffs required for future success (Schoemaker, 2008; Tushman, 2014). That is why, similar to entrepreneurial skills, design-thinking might be beneficial to technology managers. In its simplest form, design shapes ideas to become practical and attractive propositions for users or customers. Design is not only as a problem-solving activity but also a knowledge generation and integration activity, covering a wide range of fields, activities, and tasks, including product performance, process efficiency, cost, ease of manufacturing, aesthetics, user friendliness, durability, and ergonomics (Martin, 2009). Hobday (2011 and 2012) argues that economic growth and the expansion of wealth rely in part on the design and creation of new spaces for technological possibility. These spaces, in turn, require the human ability to design and create stories, forms, and concepts that underpin business and wider economic innovation. In other words, design-thinking is a model that allows firms to integrate design into their core activities as a spur to innovation, and it becomes a critical consideration for technology managers.

Design-thinking helps to balance exploration-exploitation conflict but more importantly it induces abductive thinking (Martin, 2009). Abductive reasoning refers to the logic of what might be. This thought process is a kind of informed conjecture that can only be verified through the generation of new data (usually through prototyping and testing, in most business applications). So it is neither associated with analytical thinking (relevant to exploitation) or intuitive thinking (like in exploration). In fact, this is exactly what the November 2014 issue in Harvard Business Review (Thomke et al., 2014) invites managers to experiment with.

Further, design thinking could be instrumental in understanding multiple users across countries and markets. Dell'era et al. (2010) argue that "it is not sufficient to be sensitive only to socio-cultural messages, it is also necessary to transfer distinct inputs and stimuli into real projects in order to exploit accumulated knowledge about socio-cultural phenomena and transform it into new product meanings and languages." Even if designers can support company exposure to emerging trends in society, this 'listening' activity has to be integrated with research on technologies that allow products to embed appropriate language. This listening activity is also suggested by Verganti (2009) as a practice that a successful design-driven company should undertake. That is why Verganti calls for companies to not only work with customers as end-users, but also actively search and find 'interpreters' such as scientists, customers, suppliers, intermediaries, designers and artists who could deeply understand and shape the markets they work in. Green (2007) reports the benefits of working with cultural innovators and creative communities. Thus, design-thinking provides a powerful tool to approach problems from a different perspective by integrating variety of stakeholders into the process.

The IRI 2038 study (Farrington and Crews, 2013) highlights the importance of needs identification and speed-to-market in order to quickly identify opportunities for research and technology to serve new customer needs and understand each customer in his/her specific context. This means developing skills in culture, society, customer research, ethnography, and rapid prototyping as discussed above in innovation section. Additionally, these skills will need to be globally relevant, as managers will face with new consumers and researchers from emerging markets around the globe.

Besides the creation and diffusion of innovations for particular customer needs, culture is influential in commercialization. Both national and company culture can influence the results of innovation. Culture plays an important role which bridges invention and innovation. A study on developing a global mindset (Javidan and Walker, 2013) shows that cultural issues might diffuse into knowledge and skill sets for managers to prepare for diversity in global markets. In particular, managers aiming to become global leaders should develop their intellectual, psychological and social capital to develop their cross-cultural capacities (Javidan and Walker, 2013; Horwitch et al., 2012). Hence, we consider the following :

> Proposition 6: In parallel to the increase in entrepreneurial global markets, TM professionals should increase their knowledge on three major strategic management tools, namely entrepreneurial skills, design-thinking and cross-cultural perspective.

4. CONCLUDING REMARKS

The evidence on the need for TM education is compelling due to the three major challenges outlined above, namely (1) the intensification of innovation, (2) changing operational processes through the integration of services & manufacturing and increased concerns around sustainability and (3) the expansion of strategy to integrate new business models and importance of ambidextrous organizational structures. Since changes go beyond organizational boundaries, technology managers need to be equipped with new expertise and new skills in organizing, collaborating and communicating with a wide variety of stakeholders. This trend will increase with open innovation practices, which will influence organizational forms in favor of collaborations.

TM's overarching concern is to help management and staff to understand, develop, and implement technology for the benefit of the enterprise, customers and society. Given that need, technology managers and students with career plans in TM should find ways of preparing themselves for the future. Educators also have to find ways to respond to the new challenges.

On top of that base, technology professionals and students need to be equipped with a broad set of skills, ranging from generic to specific. While generic skills such as are taught in courses on strategy, marketing, organizational behavior, finance, project management and operations management, specific skills range from creative problem solving, business plan development and cross-disciplinary communication and they need to be integrated into new curriculum at higher education institutions.

The challenges analyzed in this paper along the lines of innovation, operations and strategy call for educational institutions to enrich their programs to integrate new managerial concepts, competencies and skills for the effective management of technology. This is not an easy task. Technology-based corporations increasingly need to build a capacity for rapid innovation in strategies, products, processes and services, as distinct from traditional high volume mass production or service companies of past decades. Thus, technology managers should acquire the knowledge and skills that will enable them to compete effectively in world markets. As discussed in this paper through propositions, TM education should accommodate:

- interdisciplinary skills
- team-learning
- creativity and talent management
- new marketing and product development techniques
- managing sustainability across the supply chain
- cross-disciplinary communication
- multidisciplinary team management
- service management
- data analytics
- new business model development
- entrepreneurial skills

- design-thinking
- cross-cultural perspective.

For future studies

Although providing the theoretical basis is an essential part of establishing a discipline, scholars should also encompass issues relating to the profession itself and the people who actually work in the area in their daily life. Considering the limited attention given to the topic in the TM literature, there is an immediate need to raise awareness of academicians. The hope is that this paper will initiate a fruitful discussion and encourage researchers to conduct studies about the TM profession in order to develop a unified professional identity.

The profession in the field of TM is facing substantial challenges. This paper brings together the influence of three major forces: innovation, operations, and strategy. It seems that the traditional management should be enlarged to embrace the new reality of not only managing internally but also collaborating externally in a global network of organizations such as customers and universities. This will lead to a change in strategy. The future of TM will shift from a top down management approach to a more open arrangement with many stakeholders involved. By designing managerial processes through a democratic involvement of different actors in society, managers can adapt themselves to future challenges. For technology professionals at all levels, from shop-floor engineers to top level technology managers, people involved in managing technology should develop new capabilities and skills to adapt themselves to face these challenges. Educational reform on TM might help managers in their endeavor to prepare for the future.

This study is an early attempt to draw attention of researchers and educators to the TM profession since the field cannot exist without its practicing professionals. We have developed propositions based on our analysis of challenges experienced in three key processes of businesses: innovation, operations, and strategy. There are many potential avenues for impactful future research in this dynamic area. The propositions reported in this paper could be examined through empirical work to verify the validity of observations from the literature review and bring new knowledge about practitioners in TM and their future expectations. Another line of research could be to observe empirically how technology professionals vary over their career path as has been done for other professionals. Other studies could concentrate on the pedagogy of TM education and the potential routes of the adoption of new educational tools and techniques.

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