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A taxonomic review of methods and tools applied in technology assessment

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ABSTRACT

Technology Assessment (TA) has been a growing field of management study for the past four decades. An increasing number of studies have been carried out over the years contributing to the development of TA literature. Some of these studies summarized the history and growth of the field during its evolution. However, there has been no effort made to present an overview of the methods and tools that have been cited in TA literature. This paper attempts to fill that void. A thorough review of the TA articles published in leading journals in the management of technology field is conducted to identify the research methods or tools in those studies. The paper provides an introductory review of the use of technology assessment terminology during its development, which helps the readers avoid the confusion of the TA concept since its origination in public decision making forty years ago and where it is now — widely adopted in other sectors. A thorough presentation of the approaches, methods and tools that have been introduced or employed in both mainstream TA and "inverted TA" studies is then provided. The main content of the paper is related to the works published in leading international journals that involve certain research methods or techniques.

1. Introduction

Technology assessment is an important area in technology management that has received increasing attention among researchers in both public and private domains. Even though TA has been developed over the past four decades and found its value in many technology related problems, there is still a strong need of finding more effective methods. This paper is an attempt to move in that direction. In this paper the journal articles are reviewed with a particular interest in identifying what approaches, methods, and tools have been presented or employed in TA research. A keyword search for TA related articles was carried out in the leading journals of the field of management of technology (MOT). These journals were selected based on the two articles that studied the citations of leading journals most cited in MOT literature [1,2], including *Technological Forecasting and Social Change, International Journal of Technology Management,* and *IEEE Transactions on Engineering Management* just to name a few. As the term technology assessment has been picked up by various researchers in the business and non-governmental sector to refer to different research purposes since its origination, the key words used in the search include both directly related terms including technology assessment, technology evaluation, technology selection, technology choice, technology audit, and technology appraisal and indirectly related words such as technology forecasting, roadmapping, appropriate technology, technology scanning, adoption, and transfer. The timeframe of the searched journal articles is between 1970 and March 2007. The broad spectrum of the search helped to ensure the inclusion of relevant articles to the study. A scanning of the search results gave a list of about 200 articles that are considered relevant to the research interest. These articles were then reviewed to identify the topic of the subject. Special consideration was given to those that utilize or introduce any formal research methodologies. These assessment methods were introduced and categorized in a manner that helps the readers get the best sense of the overall picture. Out of the reviewed articles, 75 are cited in this paper. The remaining papers were irrelevant to the topic of the paper.

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A number of studies provided classification for research on TA methods. One example is a *Technology Assessment Primer* published by IEEE in 1975 [3]. This work included papers of many prominent researchers in the TA field. It reviewed the fundamental issues in TA such as the TA concept, why TA, TA scope and presented some TA samplers. Another classification work by De Piante Henriksen [4] introduced a comprehensive summary and classification of various techniques and methods that are applicable. These techniques and methods were grouped into nine categories, ranging from economic evaluation to impact assessment along with good sources of reference materials of the techniques. There is an overlap between the groups identified in these studies and what we had identified. The distinction made between methods used in public and business and non-governmental areas is the major contribution of this paper. The analysis clearly identifies different shifts in both areas.

2. Defining technology assessment

The concept of TA was first developed in the United States in the late 1960s, and the Office of Technology Assessment (OTA) was established in 1969–1972. TA has its origins in the policy needs of the U.S. Congress as perceived by one of the committees of the House of Representatives chaired by Emilio Q. Daddario. Its goal was straightforward but by no means simple to achieve. The committee saw that Congress needed an earlier awareness, an earlier warning, and an earlier understanding of what might be the social, economic, political, ethical and other consequences of the introduction of a new technology into the society or a substantial expansion of an existing technology. Consequently, without any doubt TA was conceived as a concept to assist in public policy decision making. Its goal of informing and improving government decision making implied, of course, that the researchers also informed the thoughts and deliberations of a wider public concerned with policy toward new technologies.

As early as 1976 Joseph F. Coates defined TA as “the name for a class of policy studies which attempt to look at the widest possible scope of impacts in society of the introduction of a new technology. Its goal is to inform the policy process by putting before the decision maker an analyzed set of options, alternatives and consequences” [5], and as recently as 2001 he redefined the concept along that line as “a policy study designed to better understand the consequences across society of the extension of the existing technology or the introduction of a new technology with emphasis on the effects that would normally be unplanned and unanticipated” [6]. Under this context the TA terminology was meant to refer to public decision making and resource allocation. However, in the early stages of the concept, business and industry executives saw that it was an interesting term that might be somewhat useful. Therefore, extensively across the American industry, technology assessment was adopted as a term having absolutely nothing to do with the U.S. Congressional meaning of it but basically as a general rubric for the concept of technological readiness. Is the technology ready, or will it be ready, or when will the technology be ready to meet some business organizational or manufacturing production use or applications goal? Coates and Fabian [7] found that many of these companies viewed TA solely in terms of trying to anticipate the effects of the outside world on their own activities, rather than anticipating the effects of their activities on factors outside of themselves. They called this approach “inverted technology assessment”. Without denying the informative value of TA in industrial settings, they argued that to use the term technology assessment – a term that, whatever its own shortcomings, is now firmly attached to public policy impact assessment – to describe parallel, but fundamentally different, corporate planning activities is a mistake. Maloney [8] showed how TA in the private sector differs from that of the public sector in four main dimensions: objectives, structure, timeframes, and other perceptions. His study recognized that private sector conduct TA studies with an objective of maximizing profit with a short to mid term view as opposed to the public sector.

This paper does not aim to dwell on the problem of misuse of the terminology in the business and non-governmental sector; however, it is interesting to see how the term technology assessment has been widely adopted in TA research that has nothing or little to do with public decision making. A keyword search in international journals yielded numerous returns of the TA term along with its many variations including technology evaluation, technology audit, technology appraisal, technology selection, and so on. A large number of these papers were submitted by authors from business and non-governmental sectors. They are academic researchers, corporations, research groups and institutions, or non-affiliated researchers.

While honoring the mainstream TA research, we would also like to know how the activity has been adopted and evolved in the non-mainstream sectors with the anticipation that this branch of TA research will be growing fast in the future. Inverted TA in fact deserves more attention as it is considered to be one of the main themes in TA for the 21st Century [6]. The primary interest of this paper is, however, not to review the subjects or topics of that research, but to look for the methods and tools that have been presented or applied. We wish to gain a general picture of the research methodologies in the field, and thus inform future researchers of the methods and techniques available for their use. The main content of this paper is divided into two separate sections, one presenting the works in mainstream TA, i.e. public decision-making TA, the other examining the inverted TA research, i.e. business and non-governmental TA. Since the debate over the proprietary use of the term TA for public decision making or business and non-governmental sectors has not yet been settled, we deliberately use the TA term for both sectors throughout the paper. In fact, certain research methods and tools can be applied in both public and private settings, for instance the three-perspective TA approach, or decision analysis. Yet readers are urged to keep in mind the distinction between the conventional meaning of the TA term and its inverted application found in the present literature.

3. TA approaches and methods in the public decision-making domain

Technology assessment has been an established field of research in the public decision-making domain since the birth of the OTA in 1969. Through four decades of development, various approaches and methodologies have been introduced to conduct TA research in this field. One of the first papers that presented a systematic introduction of the research methods in TA was the work done by Coates [5] in which the author reviewed a rich collection of analytic models used in TA ranging from macro-system dynamic, land use, medical, and energy to social impact models. Van den Ende et al. *et al.* [9] classified the approaches and methods of TA into a common framework based on method types and method scopes. They also proposed the use of certain research methods according to the phase of the technology and degree of polarization in public opinions, namely Delphi, impact assessment, consumer constructive TA (CTA), participatory TA (pTA), etc. Another framework provided by Linstone *et al.* [10] used multiple perspectives for TA and other decision-making areas. The approach called for careful examination of the technology at hand from three perspectives including an organizational/societal perspective, a personal/individual perspective, and the conventional technical perspective.

3.1. Structural modeling and system dynamics

A group of techniques called Structural Modeling and System Dynamics techniques became popular in TA research in the late 1970s. Along with the advances in the systems theory field, the techniques in this area have been developed and widely adopted in other fields of study including TA. In their project, Linstone et al. *et al.* [11] conducted a comprehensive study of about 100 computer-based structural modeling techniques. Seven of them were tested by applying the techniques to TA problems, including Interpretive Structural Modeling (ISM), Electre, SPIN, IMPACT, KSIM, XIMP, and QSIM. Their work concluded with some recommendations regarding the use of these models in performing a TA. In a similar article, Watson [12] discussed the application and limitations of Interpretive Structural Modeling (ISM) – a computer-aided method for developing a graphical representation of system composition and structure – in a TA problem. In a more recent article, Keller and Ledergerber [13] introduced the Bimodal System Dynamic Approach to the technology assessment and forecasting problems. Wolstenholme [14] reasoned that the traditional approaches to technological evaluation were static and either high level and simplistic, or low level and complex. Further, they tended to evaluate a technology in terms of itself, rather than the domain it was intended to support. He proposed a three-stage methodology based upon a system dynamics simulation modeling technique to overcome these shortcomings.

3.2. Impact analysis

Impact analysis has been one of the main themes of public policy TA. A number of journal papers were dedicated to this topic. As early as in 1974 Coates [15] introduced the methods and techniques for Comprehensive Impact Assessment, e.g. Delphi, cross-impact analysis, extrapolation, decision and relevance trees, etc. Ballard and Hall [16] applied Integrated Impact Assessment to the case of the Western Energy Study as one of the first products of the Integrated Assessment Program established by the EPA's Office of Energy, Minerals, and Industry (OEMI). The approach focused on four aspects of the technology: the social and political context, the analytical approach, organization and management, and participation and utilization strategies. Smith and Byrd [17] assessed the impact of a standardized container recycling system on several aspects such as energy, economics and labor, solid waste, and others. Recently, Palm and Hansson [18] proposed a new form of technology assessment that focused on the ethical implications of new technologies: Ethical Technology Assessment (eTA). eTA could be conducted on the basis of a checklist that refers to nine crucial ethical aspects of technology: (1) dissemination and use of information, (2) control, influence and power, (3) impact on social contact patterns, (4) privacy, (5) sustainability, (6) human reproduction, (7) gender, minorities and justice, (8) international relations, and (9) impact on human values.

3.3. Scenario analysis

Another group of TA research employed scenario analysis as its research method. Scenario analysis is a well-established methodology widely adopted in many management fields. It is particularly of value to TA problems. Diffenbach [19] developed a compatibility approach to scenario evaluation which goes through three steps: problem formulation, scenario compatibility, and compatibility assessment procedure. The paper's author claimed that this method represented a significantly different combinatorial approach for scenario evaluation. Chen et al. *et al.* [20] used long-range scenario to assess aviation communication technology. Winebrake and Creswick [21] applied AHP in conjunction with a Perspective Based Scenario Analysis (PBSA) to evaluate five fuel processor technology alternatives with respect to numerous criteria and decision-maker perspectives. Recently, Banuls and Salmeron [22] argued that traditional approaches to the assessment of technological opportunities considered the future impact of each technology in isolation. Thus they proposed a Scenario-Based Assessment Model (SBAM) that allowed decision makers to measure the impact of technology interactions in a technology portfolio. The methodological framework of SBAM is a mix of the AHP, Cross-Impact Method (CIM), and Delphi Method.

3.4. Risk assessment

One TA theme that has also received attention of the researchers is risk assessment. Hellstrom [23] discussed the impact of “negative synergies” between complex technologies, social institutions and critical infrastructure with the example of food producing technologies. He then outlined a general framework for “responsible innovation” within which technology assessment and management of such systemic innovations could be carried out. Wilhite and Lord [24] assessed the risk of technology development with an Internet-Accessible Technology Risk Assessment Computer System (ITRACS) — an Internet-based software system that allowed assessment of technologies by individual evaluators in different locations. Based on a modified AHP, the tool enabled each team member to individually estimate the probability distribution of each technology and programmatic risk metric. After all individual assessments were entered via the Internet, the ITRACS software combined them into a single collaborative estimate of the probability over the value range of each metric.

3.5. Decision analysis

Decision analysis methods were also applied in some research. Merkhofer [25] presented a TA process based on decision-making techniques comprising problem definition, alternative generation, deterministic analysis, probabilistic analysis, informational analysis, and policy evaluation. Ramanujam and Saaty [26] applied the well known Analytic Hierarchy Process (AHP) technique to technological choice in the less-developed countries. Besides widely known methods, the TA literature also includes many other tools and methods that are specially developed to suit the objective of the research. Lough and White [27] developed a synthesis of TA, group idea generation techniques, and decision analysis for the Electricity Utility Planning. Nguyen et al. *et al.* [28] presented a five-task methodology to assess the information technology which aimed to make explicit the social controversies of a technological innovation. Berg et al. *et al.* [29] introduced a value-oriented policy generation methodology for TA. Their six-step assessment procedure consisted of goal clarification, goal realization status, analysis of conditions, projection of developments, identification of policy options, synthesis and evaluation of policy options. McDonald and Schrattenholzer [30] assessed the energy technologies as a function of a learning curve.

3.6. Environmental concerns and integrated TA

Since the late 1990s the TA field has seen new developments in methodologies and approaches. The environment has become a major concern in the world and in TA research. Loveridge [31] presented and discussed the similarities and interdependence between two TA approaches: the traditional Technology Assessment (TA) and the Environmental Impact Assessment (EIA), which had been stipulated in TA research in the USA and Europe in recent years. In their article in 1996, Bohm and Walz [32] applied Life Cycle Analysis (LCA) in their study and concluded that LCA was the latest development in environmental assessment and a promising methodological tool to be used in analyzing the environmental impacts in TA studies in the future. In a different research direction, Hadjilambrinos [33] introduced the notion of the “technological regime” and its dimensions as an analytical framework to evaluate technological systems. Mori [34] described an extended version of an integrated assessment model called MARIA (Multiregional Approach for Resource and Industry Allocation) and how it was applied to develop global and regional greenhouse gas (GHG) emission scenarios. The model was developed to assess the potential contribution of fossil, biomass, nuclear, and other energy technologies and land use change to future GHG emissions. Kameoka et al. [35] presented a technology foresight program in Japan that aimed to grasp the future trends of social needs and technology advancement to promote the strategic technology policy. Berloznik and van Langehove [36] proposed an Integrated TA (ITA) in R&D management practices. Goulet [37] put forward a methodology for participatory TA. Cruz-Castro and Sanz-Medendez [38] presented the application of parliamentary TA in European countries. Genus [39] reviewed selected literature focusing on the notion and practice of constructive TA. The past and future of the CTA method was also discussed in a paper by Schot and Rip [40].

A recent special issue of the *Technological Forecasting and Social Change* was dedicated to the theme of integrated assessment. The papers presented in the issue aimed to assess the uncertainties in greenhouse gas emissions and investigate mitigation alternatives from an integrated and interdisciplinary perspective. The studies extended the methodological paradigm of integrated assessment models into a broader interdisciplinary integrated assessment based on coupling detailed models of energy and industrial systems, agriculture, and forests. One salient study conducted by Tubiello and Fischer [41] provided an important analytical advance by complementing traditional climate impact analysis by also examining in detail the effects of reducing possible climate change through mitigation measures. As such, the paper fulfilled an important role in giving quantitative estimates of the benefits of climate mitigation using climate sensitive agriculture as the prominent example. Their study employed a simulation tool named the IIASA-FAO AEZ model, which used detailed agronomic-based knowledge to simulate availability and use of land resources, farm-level management options, and crop-production potentials as a function of climate. At the same time, it employed detailed spatial biophysical and socio-economic datasets to distribute its computations at fine gridded intervals over the entire globe.

3.7. Emerging technologies

Most recently Assefa and Frostell [42] explored the notion of social sustainability for energy technologies. Fleischer et al. *et al.* [43] posed the problem of assessing emerging technologies and argued that emerging technologies present considerable challenges for “classical TA”, which focuses on the outcomes or impacts of a technology and thus can be performed only at later stages of technology development when societal implications can easily be identified and determined. Therefore, they called for a TA paradigm shift for emerging technologies, e.g. nanotechnologies, and suggested the use of roadmapping as a methodological solution. Guston and Sarewitz [44] presented the concept of “real-time technology assessment” as a new technology assessment framework in the 21st century, which integrates natural science and engineering investigations with social science and policy from the outset into a research program. In an article published in 2003, Coates and Coates [45] suggested the opportunities for future TA tools including film, cartoons, radio, contests, coot courts and moot debates.

Dealing with uncertainty in emerging technologies also rose as a major concern in future TA works. Grubler et al. [46] presented an overview of uncertainty related research at the 2007 International Institute for Applied Systems Analysis (IIASA) conference and concluded that improved system science methods and models can help to better cope with decisions under uncertainty by both better describing the cosmos of uncertainty as well as helping to improve decision making under uncertainty. Their paper cited some of the most salient uncertainty related research at IIASA, among which the most exhaustive examination of the influence of technological uncertainty performed was the modeling study conducted by Andrii Gritsevskyi and Nebojsa Nakicenovic. Through the use of massive computations on a CRAY supercomputer, a full range of technological uncertainties including future costs, increasing returns to adoption, as well as technological interdependence and technology spillover effects were examined for a given energy demand scenario, assuming there were no climate policies. Altogether the model simulations generated some 130,300 scenarios regrouped into 520 sets of technology dynamics that span a carbon emission range between 6 and 33 GtC by 2100.

Another significant work done by the RAND Pardee Center [47] offered a framework to approach long-term policy analysis (LTPA), which might have profound implications for future TA problems. The writers argued that policy analysis in the long term has become a problem of making decisions in deep uncertainty and meeting the challenge of global environmental sustainability. Therefore, it required much more robust decision-making methods than the traditional decision-making methods prevailing today. Utilizing the recent advances in computer science, the report presented a new methodology, the “XLRM framework”, for making robust decisions in deep uncertainty conditions for LPTA problems. The XLRM framework consists of four elements. Policy levers (“L”) are near-term actions that comprise the alternative strategies decision makers want to explore. Exogenous uncertainty (“X”) are factors outside the control of decision makers that may nonetheless prove important in determining the success of their strategies. Measures (“M”) are the performance standards that decision makers and other interested communities would use to rank the desirability of various scenarios. Relationships (“R”) are potential ways in which the future evolves over time based on the decision makers' choices of levers and the manifestation of the uncertainties. The method employs two types of software: exploratory modeling software and a scenario generator. In combination these two types of software enable humans to work interactively with computers to discover and test hypotheses about robust strategies. This excellent work should be of interest to decision makers, including technology assessment and policy decision makers, concerned with the long-term effects of their actions, those who conduct long-term planning, and anyone who deals more generally with decision making under deep uncertainty.

4. TA approaches and methods for business and non-governmental uses

Since the closing of the OTA, research interest in the field has shifted to other countries, particularly European countries, and other sectors. Business and non-governmental research institutions such as universities, corporations and individual researchers have picked up the TA areas and deliberately used the term to refer to various business and non-governmental applications such as economic and performance evaluation of technology alternatives, selection and acquisition of strategic technologies, strategic technological planning, and so on. This is apparently a deviation from the historical and conventional applications of TA in the public domain, and is in fact considered an inverted form of TA. While the debate on the definition of TA remains unsettled, we argue that these activities provide value to the business and non-governmental decision-making applications, and hence more study of this field should be conducted.

4.1. Cost benefit analysis methods

One of the most popular research methods observed in this branch of TA literature is the Economic, or Cost Benefit Analysis (CBA), method. It was among the most popular TA research methods applied by corporate researchers. Gagnon and Haldar [48] conducted a survey of US engineering managers on what criteria and methodologies they employed to evaluate new engineering technologies. Their findings showed that total savings, break-even point period, internal rate of return, accounting rate of return and total raw cost were the most cited financial criteria by the engineering managers. Tipping and Zeffren [49] developed an evaluation approach called the Technology Value Pyramid (TVP) and introduced a comprehensive Menu of Metrics, which comprised 33 evaluation metrics ranging from financial ratios to organizational measures to determine the value of R&D investments in the corporation. Based on the reasoning of real options in finance, McGrath and MacMillan [50] introduced a process of Strategic Technology Assessment Review (STAR©), which investigated various variables including the size and sustainability of potential revenue streams, speed or delay in market adoption, development costs, commercialization and market access costs, company strengths, likely competitive responses, dependence on standards, and the degree of uncertainty. They argued the major advantage of this approach was that it integrated both technological and strategic considerations. Evaluating the investments in advanced manufacturing technologies (AMTs), Ordoobadi and Mulvaney [51] developed a tool known as System Wide Benefits Value Analysis (SWBVA) to assist decision makers. Users of the tool first performed an economic analysis to see if the investment was economically justified. If it was not yet justified, the gap between the minimum desired economic return and the actual return amount would be calculated. Users could follow a series of procedures to determine if the value of the system-wide benefits associated with the advanced technology was sufficient enough to justify this gap.

The economic analysis methods were, however, usually criticized by the TA practitioners when applied to technology assessment problems, and some researchers seek to modify the methods or use multiple approaches to the evaluation problem. Chau and Parkan [52] argued that the choice of a manufacturing process solely based on the cost analysis was not adequate since the process with best direct cost performance might not prove to be the best overall. Thus they adopted a two-pronged approach, which involved a regression analysis to determine the rankings in direct costs and a distance-based multiple attribute decision-making method called TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) to identify the rankings with respect to operational benefits. Then, the two results were combined in a manner to reflect the subjective views of the decision makers involved to make the final selection. Hartman [53] proposed the construction of a so-called Technology Balance Sheet that complemented the trade balance sheet to evaluate a company's technological potential. The technological and financial assessments could be consolidated into an overall evaluation to come up with the true value of the technology. Gagnon [54] proposed a method: first, integrate traditional financial discounting procedures for known cost data with expert opinions for estimating benefit values of the technologies and second, incorporate engineering performance improvement, project volumes ranging from one to infinity, various time horizons, and a comprehensive sensitivity analysis. Sohn and Ahn [55] showed how a multigeneration technology diffusion model can be applied for more accurate CBA for information technology. In a review paper, Boer [56] clarified the problems commonly encountered in the economic evaluation of technology practice, for instance miscalculating horizon value, focusing too narrowly on cash flow, or overweighting the analytic (versus the synthesis) approach.

4.2. Decision analysis

The second group of methods of common use was decision analysis techniques, particularly the Analytic Hierarchy Process (AHP). The popularity of this group of techniques showed that many of the researchers in this TA field were academic people, engineers and scientists, especially at project and industry levels. Bard and Feinberg [57] conducted an assessment of the electric and hybrid passenger vehicles in which they applied the Deterministic Multiattribute Utility Theory in the first phase and Monte Carlo simulation in the second phase. The result was optimal allocation of funds to different projects of the chosen technology. Prasad and Somasekhara [58] employed a combination of the Delphi and AHP methods for choosing technologies in Indian telecommunications. Raju et al. *et al.* [59] assessed five technological alternatives in soap-making that are ranked by the application of AHP. Their study showed that the technology rankings were a strong function of the development perspective of the decision maker. In another study, Prabhu and Vizayakumar [60] developed a method called the Fuzzy Hierarchical Decision Making (FHDM) method that synthesized the concepts of the Multicriteria Decision Making methodology and fuzzy analysis. The paper illustrated the use of FHDM for the technology choice of iron-making technologies via the help of software developed by the authors. Meade and Presley [61] utilized the analytic network process (ANP), a general form of Saaty's analytic hierarchy process, as a model to evaluate the value of competing R&D project proposals.

4.3. Measures for technology

Technometric measurement was also widely used by many researchers, especially engineers and technologists. Koschatzky and Frenkel [62] constructed a profile that showed graphically the performance characteristics for selected key attributes of the product, process, technology or the industry. Geisler [63] presents a more detailed and comprehensive review of the technology evaluation metrics, including econometric methods, patents, process methods, and bibliometrics. Some other authors used specialized measures that were specific to their technologies. Barbiroli [64] identified 16 parameters to evaluate the global advantage of a new technology, ranging from process reliability to change in the technological balance of the technology. Esposito [65] introduced a composite approach to technology measurement. Majer [66] employed the functional approach to a similar problem. Sahal [67] developed a sophisticated discriminant analytic framework for the measurement and assessment of technology.

4.4. Roadmapping

Increasingly, many researchers have employed roadmapping, an emerging effective tool in their TA studies. Roadmapping has been utilized widely in MOT as a forecasting and planning management tool. Technology forecasting was considered by many researchers as an integrated part of TA, and thus roadmapping can be used in TA studies. Koen [68] presented two new technology maps, namely the Enabling Technology Map and the Source of Technology Map, as tools to guide technologists to focus on technologies which provided competitive advantage to the company while outsourcing the more mature technologies. Holmes and Ferrill [69] followed a five-step process to help the Singaporean SMEs create their first Operation and Technology Roadmap (OTR).

4.5. Scenarios and Delphi

Thomas [70] proposed a scenario planning model to aid corporate management in planning strategic technology management, future products and competitive advantages. The Delphi technique seems to be widely adopted in many studies thanks to its strong validity in management fields. This technique was usually used in conjunction with other methods in TA. However, Titchy [71] pointed out the bias often seen in Delphi techniques, as top experts tend to give the most positive assessments to the problems at hand, and called for a fair mix of experts involved in the technique. Surveying is a long-established research method and is also utilized in many TA studies, mainly as a data collection tool.

4.6. Surveying, information monitoring, new technology assessment

Surveying was also a popular method to gather data for the research. Owolarafe and his colleagues conducted surveys to assess the oil extraction technologies in Nigeria in 2000 and 2003 [72,73]. Yap and Souder [74] presented a two-phase filter process for technology evaluation and selection process with the application of the linear programming method. Patent analysis has recently risen as a new study method in the R&D field, and was adopted by Slowinski et al. *et al.* [75] in their study. Their paper presented a technology evaluation method called "IP Asset Valuation" applied to early stages of development when the classic asset valuation method based on discounting future free cash flow from an investment will be problematic. Jeong and Kim [76] proposed a qualitative cross-impact approach by using fuzzy relational compositions to assess a technology portfolio. Benson et al. *et al.* [77] developed a Triple-Gateway methodology for evaluating emerging technologies at a very early stage of their development, when it is still possible to avoid costly investments that have little promise. Pretorius and de Wet [78] applied a 3-dimensional structure to assess new technology with hierarchy, fundamental functions, and the business cycle as the axes.

4.7. Mathematical and other synthesis methods

Apart from the tools and methods that have been long established in theory and practice, the literature also found unique methods that were developed by the researchers to cater for their specific research purposes. These methods represented a diverse collection ranging from qualitative to quantitative methods, from sophisticated mathematical models to broad perspective conceptual frameworks. Among the examples are two mathematical models developed by Sharif and Sundararajan [79] and Liang et al. *et al.* [80]. Sharif and Sundararajan's model involved four steps: 1) identification of factors that affect the selection of the technology, 2) classification of all identified factors, 3) formulation of a general model in terms of the classification, and 4) quantification of the terms of the model. Liang's work helped select the best technology strategy based on the concept of technological dominance. They provided a hierarchical structure for the strategy selection problem by combining the concepts of technological selection and technological forecasting. Chapelet and Tovstiga [81] developed a diagnostic methodology which could be used to assess the competitive impact of a firm's use of technologies to support its business processes. Rosenfelder [82] suggested the use of an advisory committee as a tool for new technology assessment in multi-divisional firms.

5. Discussion

Within the studied literature two distinct groups of journal papers were observed chronologically. The first group includes the papers that were published in the journals during the 70s, and the second from 1980 until the present. The first group is much smaller in quantity than is the second, and consists of mostly public decision-making research. This is the post-OTA era when many papers were written about the operations of the OTA. Business and non-governmental TA only took off in the early 1980s and proliferated during the 90s and early 2000s. Early public TA research employed traditional methods such as impact analysis and system analysis. However, toward the end of 1990s the focus of the methodologies has shifted to Integrated TA, Participatory TA, and Environmental TA as presented earlier in the paper. Considerable was the emergence of non-traditional methods, i.e. those developed specific to reflex a different perspective or incorporate distinct concerns. A notable example of this group is the multiple perspective TA approach.

Even though only picking up after the public sector TA in post-OTA era the business and non-governmental TA really gained momentum since this sector found value added applications of TA in its domain. As presented earlier, the business and non-governmental sector, particularly the corporate world, found the need to conduct technology assessment or technology evaluation to serve its strategic planning, e.g. technology choice or selection. As a result the scope of this research was much more limited than that of public decision-making TA, and so were the methods employed in these studies. The predominant categories used in these papers were economic evaluation, decision making, and technology measurement methods. It is also necessary to see the different perspectives of these studies. While economic evaluation methods reflected the economic point of view of the corporate decision makers, decision analysis and technology measurement techniques tended to represent the technical people's angle, particularly the academics and technologists. Overall, the business and non-governmental TA approached the TA problem from an economic or technical viewpoint, while public TA looked at it from a social perspective. This was again in relation to the coming into existence of the objectives of each domain as mentioned earlier. One development that was found common among the two sectors was the increasing introduction of methods and tools that have not been well documented in management literature. These methods and techniques, again, were developed by the researchers and tailored to suit a particular TA concern or present a new approach for TA. Along with the well-established methods in the management literature, these new tools and methods add to the proliferation and evolution of the field over time, and hence deserve appropriate encouragement among the prospective researchers (Figs. 1 and 2).

6. Conclusions, limitations and future research

Technology assessment has evolved through various stages with shifts in perspectives, focuses, and approaches. The dominant actors in the field have been parliamentary and policy-making bodies; however, the subject was later also picked up by researchers from the academy and the industry. The paper clarifies the distinction between mainstream policy formulations-oriented TA and its variations. A wide range of methodologies has been utilized in TA works ranging from analytic techniques to integrated impact-analysis approaches. Policy formulation TA works typically employed more holistic and multifaceted research methodologies, while the private sector tended to utilize operational methods and tools. Even though the debate about whether the term TA should be used to refer to both public and business and non-governmental TA remains unsettled, the existence and value of "inverted TA" to the business and non-governmental sector should be acknowledged as a part of the inevitable evolution of the management field for it is expected to continue grow resiliently in the coming years.

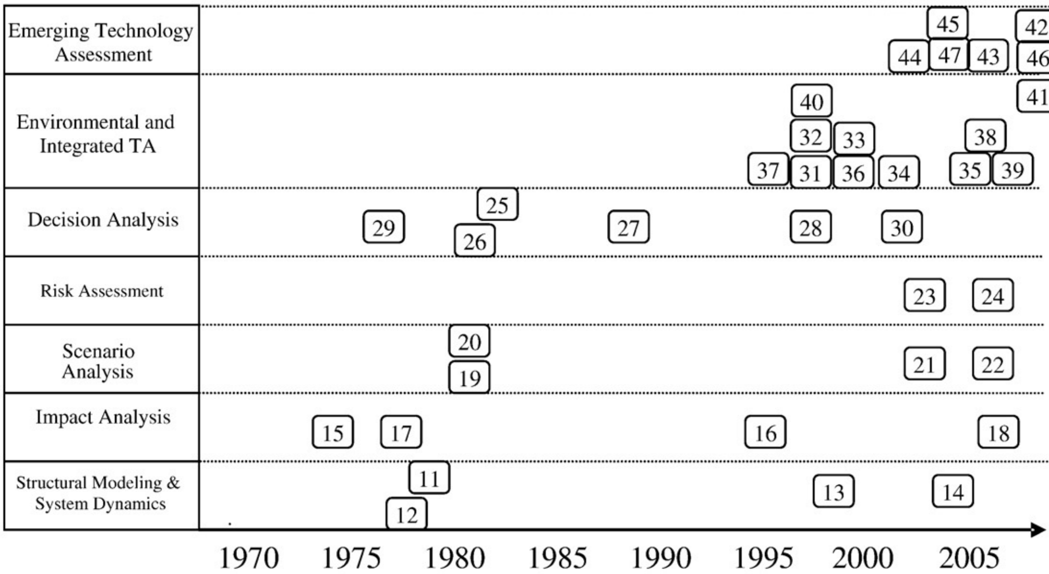

Fig. 1. Categorization of TA papers in public decision-making domain.

Also from this review we can see that TA researchers are equipped with a diverse pool of theory-based tools and methods that are still growing in number and form. However, there are no universal tools or methods that can be applied in all TA studies. TA is an evolving area that continuously brings in new issues and challenges to the researchers and thus requires the invention of new methodologies and approaches to meet the new demands of the field.

Our objective was to investigate the application of research methods and tools in TA research that have been published in leading MOT journals since 1970 and thus to provide researchers with a general picture of existing methods that can be used for a TA study. In addition to accomplishing our objective, we also uncovered the need for modification and development of methods that are better suited to a particular TA research. The paper, however, only reviewed journal literature as the primary source of information, thus does not represent the entire body of technology assessment literature. This work can be considered a part of a more comprehensive review of TA methods and tools. Future work should embrace the much richer body of TA literature, particularly the work that was done at the National Science Foundation and the Office of Technology Assessment.

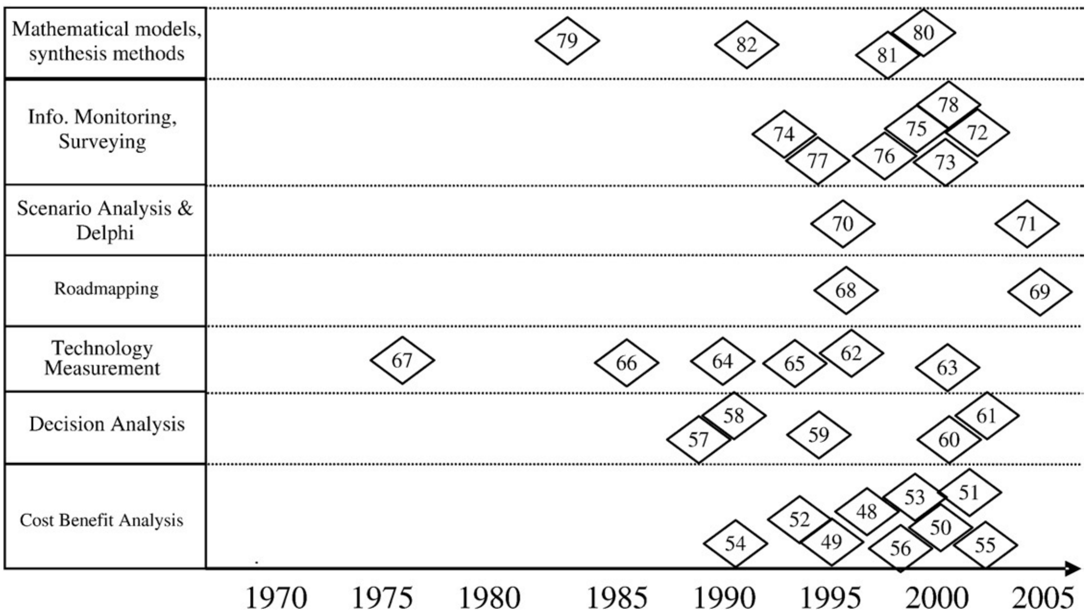

Fig. 2. Categorization of TA papers in business and non-governmental.

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