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Technology forecasting (TF) and technology assessment (TA) methodologies: a conceptual review

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Abstract

Purpose – Technology forecasting (TF) and assessment (TA), all in all, apply to any intentional and deliberate endeavours to forecast and view the potential heading, rate, attributes and impacts of technological change, especially for development, advancement, selection and utilisation of resources, which ultimately helps in the benchmarking. A vast variety of methods are available for TF and TA. Till now, practically, no exertion has been made to choose proper, satisfactory innovation methods or technology. The paper aims to discuss this issue.

Design/methodology/approach – In this paper, there is an endeavour to summarise the vast field of TF and TA, through its evolution, functions, applications and techniques. This paper provides the in-depth review of the utilisation of TF and TA methodologies and its improvement, which helps the users in selecting the appropriate method of TF and TA for a specific situation.

Findings – This study concludes that the quest for a single strategy for doing forecast and assessment is a misconception. This neglects to perceive that forecast and assessment oblige a suitable blend of strategies and methods drawn from a variety of fields. Researchers and practitioners must be innovative, imperative and specialised in choosing TF and TA methodologies, and cannot be programmed.

Practical implications – The technology seems to be the most significant driver of the present day global developments. Some technologies have far-reaching implications, and the authors need to understand these issues regarding its' forecasting and its assessment.

Originality/value – The decision of proper worthy procedure amid a circumstance may have an impact on the exactness and reliability of the forecast and assessment. Significant observations regarding learning, action/s, actor/s and expected outcomes are discussed.

Keywords Benchmarking, Literature review, Technological forecasting, Technology assessment, TF and TA methodologies, Techniques of technology forecasting

Paper type Literature review

1. Introduction

Business organisations have been implementing modern technologies to encounter present challenges towards new/better products, processes/activities, services and practices for delivering higher efficiency and effectiveness (Kumar *et al.*, 2015). Analysis of the implications of new or emerging technologies has become a necessity for the economies,

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organisations and societies. This analysis does not only help in cost-effective solutions, but is also vital for identifying the best suitable alternative ranging from individual level to the global level. These analyses are the methodologies of technological forecasting (TF) and technology assessment (TA) that help in making a well-informed decision and setting priorities for research and development (R&D). TF and TA also help in exploiting the available knowledge and understanding, as well as managing the risk of emerging technologies and innovations. As the business environment is extremely competitive in public as well as private sector, TF and TA are used to satisfy the rising needs of the innovation (Huang *et al.*, 2014). Generally, a country's economy depends upon the innovations to keep up and enhance living standards. In today's global world, countries are interconnected for the advancement of the economy (Bijker, 1992). Along these lines, TF and TA are more imperative and hard to target for investigations to help decision maker (Ely *et al.*, 2014). Technological forecasting and evaluation will generally rely on the perspectives of the overall population and their constituent agents about financial competition, technological advancement and the technological improvement (Jun, 2011; Compagna and Kohlbacher, 2015).

The best analogy for TF and TA is climate forecasting. This is a brilliant TF, which permits, arranges, decides and encourages expanding gain and minimising losses for the future conditions. In the case of climate forecasting, people verifiably figure the climate by their option of whether to wear a waterproof coat, convey an umbrella or put the sunscreen, etc. (Mishra *et al.*, 2002).

Any individual, or association, or country that may be influenced by the change in technology takes part in forecasting and assessment of technology in every sphere that dispenses assets to express purposes (Un and Price, 2007).

Benchmarking is a technique that compares the performance outcome of an organisation with the available technologies and the best practices of other organisations (Tasopoulou and Tsiotras, 2017). The application of the benchmarking is to focus on the identifying and understanding the detailed organisation procedures and after that comparing the organisation performance with that of other organisations (Guimaraes and Langley, 1994; Moriarty and Smallman, 2009). Managerial teams conduct the process of benchmarking using the results of TF and TA (Adebanjo and Mann, 2000; Daim and Dash, 2011). The first step of benchmarking is to identify and assess the available technologies and the outcomes of the organisation. In the next step, benchmarking is done using and comparing the available TF results or comparing the organisation performance with the competitive organisations. The shortcomings in the process or outcomes of the organisation are assessed using TA. In this way, a performance gap is established, and the elements, which have led to superior performance, are understood (Sharif, 2002). The final step is to formulate an improvement plan and implement the actions necessary to close the performance gap.

1.1 Objectives of the research

More than 80 per cent of the organisations are of the view that TF and TA are unstructured and unsystematic processes, and there is a need for improvement (Reger, 2001; Firat *et al.*, 2008; Kerr and Tindale, 2011). In this paper, an attempt has been made to identify respective tools for TF and TA. Both are the multidimensional processes and highly subjective. Many of the tools used for TF and TA may come with some customisation. This review work helps in exploring the objectives, as follows:

- to explore the historical evolution of TF and TA;
- to identify respective tools/methodologies for TF and group them under families;

- to analyse relationships among TF methods to explore limitation of these identified families; and
- to identify respective tools/methodologies for TA.

1.2 Methodology

The organisations use the number of different tools and methods with varying intensity for TF and TA. They do not have a clear idea about the distinctive method of TF and TA and where to use the TF method and where to use the TA at what intensity. From a methodological point of view, the literature review is comprehensive, and its content analysis was undertaken. We go through papers of over a wider horizon from 1960 to 2015. After going through all the available papers on Web of Science, Scopus and universities press sites, TF and TA methodologies and applications are summarised.

This study addresses numerous overlapped forms of forecasting technology and assessment methods and their effects. First, this paper offers the list of different methods of TF and then categorises them into eight major families. After that, the in-depth review of TA and its methodologies are presented. Authors' endeavour is to provide suggestions on the applicability of different methodologies as the case requirements. This paper gave a brief rundown of the groups of TF and techniques of TA and bolstered that the forecasting and assessment incredibly rely on upon fitting the choice and utilisation of proper technique. This paper also suggests that TF and TA are multidimensional activities.

We have organised the paper into seven sections. Section 2 deals with the TF and TA evolution over time. Section 3 presents various methods of TF, whereas Section 4 deals with the analysis of the relationship among identified TF methods and systematic analysis of limitations of TF followed by the need of TA and description about tools for TA in Section 5. Sections 6 and 7 present the discussion of findings clearly showing managerial implications and unique contributions of the paper and concluding remarks, respectively.

2. The evolution of TF and TA

The evolution of both (TF and TA) has been divided into two parts, i.e., first, before and, second, after the Second World War. Before the Second World War, the essential authority record of an exploratory point of view towards the long running of innovation and advancement of science which happened in 1935. National Resources Committee (1937) report suggested fundamentally about the outcomes of technological changes (Schnaars, 1989).

After the Second World War, the USA tried to investigate post-war effects mostly with the diagrams of statistical approach (Bush, 1990) and the USA focussed absolutely on the pace of innovative correction and technological change after the Sputnik stun. This accentuation likewise increases the needs of the US defence system where they can be focussed on progressive eras of weapons frameworks. As an outcome, the R&D administration system has been formed in both industry and government, which helps in setting up labs, funding research and building up research group (Roussel *et al.*, 1991). War yielded the need to address sensational improvements in innovation like guided rockets, atomic weapons and figuring. Framework investigation turned into a fundamental device in arranging such propelled frameworks. By 1949, basically, underneath the US Government, the improvement of TF as an exploratory method for investigating the eventual fate of innovation was underway. TF helped strategists of the military to manage the quality and lead times important to create an edge. Quantitative exploratory studies are based on taking data from the past and predict the future. It includes the development of models and pattern extrapolation. Regularising estimate, beginning with perceived future needs, is assumed a part too. The blend

likewise encouraged more subjective methodologies, for example, significance trees (Esch, 1972), mission stream examination, situation composing and Delphi (Gordon and Helmer-Hirschberg, 1964).

TF and TA were constructed to support industry, government and the educated community (Jantsch, 1967). In the 1960s, books and journals on TF and TA reached out a long-way past the US defence system. In the 1970s, disillusionment with frameworks investigation starts to spread with the disappointment of its capacity to manage ill-organised frameworks (e.g. Vietnam). In 1973, oil-stun uncovered a percentage of the impacts of geopolitical dangers on the forecast of innovation fates.

Hence, the support for TF and TA in policymaking has been started in the 1980s as it was understood that the instabilities of technology advancement challenged obvious "system analysis" arrangements.

There was additionally developing acknowledgement started a while ago that acknowledged scientific paradigm procedure, for example, approval and replication could not be connected to affirm the forecasting tool beyond the close term (Zhu and Porter, 2002). These are worries that will be enlightened in the discourses of numerous points of view and started the segment on the methodologies and tools for TF and TA. Technology-intensive firms with started to shift towards decentralised R&D administration and the second era of R&D administration systems. TF and TA reduce the practise in a set of tools; the use of forecast and assessment somewhere around 1975 and the mid-1990s was generally very less, for the most parts were ineffectively characterised and executed without much thoughtfulness regarding formal presumptions, time horizons or impediments (Coates *et al.*, 2001).

From the evolution of TF and TA, we may conclude with the following observations.

Observation 1: TF and TA may be recognised as an important area that needs to be explored in terms of tools/methodologies of TF and TA towards achieving business viability, securing profitability, and gaining competitive advantage for firm/supply chain and helping the human race by providing innovative and sustainable products/services/solutions.

Observation 2: however, some literature on the evolution of TF and TA is available, but there is a strong need to identify and analyse TF and TA tools/methodologies relevant to new product development (NPD).

3. TF methods

Settling on vital choices for TF method is a standout amongst the most troublesome difficulties for the R&D staff. As Ralph Lenz, US aviation-based armed forces innovation forecasting pioneer once said, "TF may be characterised as the prediction of the development, qualities, measurements, or execution of a machine serving some valuable need" (Slocum and Lundberg, 2001; Martino, 2003). Mishra *et al.* (2002) said that "Emphasis on TF method" and "Development of methodology to select an appropriate technique for TF is vital requirement of sustainable development".

3.1 TF families and associated methods

There are numerous methods of TF, which can be fit in under eight families (expert opinions, trend analysis, monitoring and intelligence methods, statistical methods, modelling and simulation, scenarios, value/economic/decision methods, descriptive and matrices method). Table I explains these identified TF families and the associated methods.

The TF methods have been identified from the relevant literature and fitted into eight families by utilising experts' advice. From Table I, we may conclude with the observation and sub-observations as provided below.

Table I.
An overview of TF families and related TF methods

TF family and TF methods	Brief description	Conditions for using TF methods
1. Expert opinions Focus groups (workshops, panels) Delphi Participatory techniques Interviews	Expert opinion incorporates forecasting or comprehension innovative improvement through serious counsel with specialists. In this group, the most prevalent strategy is the Delphi method. Delphi technique consolidates expert conclusions. It concerns with the probability of understanding the technology, which is proposed in the work of Haque *et al.* (2013). In this technique, there is a grouping of personals suggestion is trailed by supposition criticism got from dissecting the introductory reaction data. The feedback which is incorporated in the thought process or support which is behind every personal will help the experts in forecasting. It permits other experts to modify their forecast by considering the new data (Levary and Han, 1995). Delphi is being the most broadly utilised procedure and has been subjected to examination by numerous creators. Woudenberg (1991) has talked about the precision and dependability parts of Delphi. His decisions are in light of the work of numerous different specialists, such as Dalkey and Helmer (1963), Campbell (1966), Pfeiffer (1968), Dalkey (1969), Farquhar (1970), Martino (1970), Gustafson *et al.* (1973), Hill and Fowles (1975) and Parente *et al.* (1984)	Expert opinions are generally used when there is a little or no past data available or in the condition when organisations want to maintain the secrecy of their end-product, process, services or technology before introducing time
2. Trend analysis Trend impact analysis Trend extrapolation Growth curve fitting Precursor analysis Long wave analysis	Trend analysis includes prediction through the continuation of quantitative past information into what is to come. It includes a broader term that incorporates monetary models and methods of forecasting, for example, exponential smoothing, regression, ARINA model, Box-Jenkins' and growth curve fitting (Levary and Han, 1995). Every technology has a life cycle made out of a few particular stages. This life cycle ordinarily consists of an introductory stage, a development, maturity and the last declining stage. In light of parameter estimation of life cycle assessment, growth curve can be determined. The growth curve technique of forecasting is useful in evaluating the maximum furthest reaches the level of growth of technology or a decrease in the phase of life cycle. It is used for determining and useful in anticipating innovation life cycle stages, i.e. when innovation will achieve a specific stage in the life cycle (Kivikunnas, 1998). One of the most common growth curve technique of forecasting is Fisher–Pry analysis. It is utilised for anticipating dissemination of innovations and applies mainly to those innovations which do not oblige significant behavioural changes. One can use nominal group technique (NGT) as a substitute for Fisher–Pry analysis which is given by Delbecq and Van de (1970)	Trend analysis methods are used to benchmark when the organisation continuously produces the technologies, product and services. It is a quantitative approach which requires enough past data for analysis and is generally used by the textile, automobile and electronics industry
3. Monitoring and intelligence methods Bibliometrics (patent analysis, text	Monitoring variations, technology watch and environmental scanning are more suitable for rolling out mindful of changes that could affect the infiltration or acknowledgement of the innovations in the commercial centre (Phillips *et al.*, 2007). Madnick and Woon (2009)	Monitoring and intelligence methods are used where researchers or industry want to explore new areas of

(*continued*)

Table I.

TF family and TF methods	Brief description	Conditions for using TF methods
mining, research profiling) Monitoring (technology watch, environmental scanning)	states "environment examining/scanning can be considered as the focal point to prospects research. However, the results are generally broad, making it impossible to bolster a particular choice". Monitoring system goal is to discover early signs of conceivably imperative innovations to pick up however much lead time could be expected (Van den Hende *et al.*, 2007). Resource accessibility is one of the scoping issues connected with these techniques since various examining methodologies oblige the utilisation of specialists (Firat *et al.*, 2008; Huang *et al.*, 2014)	development and innovations. It is mostly used by the R&D department for R&D purposes and not by the managerial department
4. Statistical methods Risk analysis demographics Correlation and regression analysis ANOVA Cross-impact analysis	A statistical model is reliant on a progression of observations, and it outlines the pattern of different variables that are of interest by establishing the relationship between them. Descriptive models utilised as a part of forecasting are usually quantitative; however qualitative models are also utilised. Descriptive phenomena are single event occasions, and like this, they are troublesome to model. In this way, the use of a statistical model requires an intensive comprehension – stretching the anticipating procedure (Firat *et al.*, 2008). In the family of statistical methods, correlation and regression analysis are the most commonly used methods. Correlation and regression analysis figure the development of the pattern of the advancement of the innovation which is similar to those of existing technology. Utilisation of this technique presupposes the data concerning the development pattern of the current technologies which are accessible	Statistical methods are used where researchers or managers want to know the significance level of the different parameters of product, process, service or technology used by the organisation
5. Modelling and simulation Cross-impact Analysis Agent modelling Input–output analysis Diffusion modelling Systems simulation (KSIM, system dynamics) Sustainability analysis Scenario-simulation (gaming; interactive scenarios) Technological substitution Economic base modelling Causal models Complex adaptive system	Modelling obliges a decent comprehension of cooperation between forecast and the hidden variables or determinants. Models can help to display the future conduct of complex frameworks basically by secluding vital framework aspects from the unessential point of interest. (Firat *et al.*, 2008) System simulation is one of the famous techniques in this crew. The significant advantage of systems simulation is that "it permits clients to hunt down the best ways to deal with a problem, confronting a test, or tackling an issue, without the danger or cost of unreasonable mix-ups" (Madnick and Woon, 2009). Given this advantage, it is conceivable to envision a system which contains all (or the same number of as sensibly conceivable) technologies and it helps to figure out which innovation has the most elevated future worth (De Holan *et al.*, 2004). Despite the fact that it is conceivable to envision the model hypothetically, the handy parts of actualising such a model would be overwhelming because the exactness of that system simulation depends on the authenticity of the data and on the way in which relationships are communicated in the simulated model	Most of the industrial problems are complex which are sometimes impossible to analyse in the real environment because of the cost factor. In that case, modelling and simulations tools are used by considering the real condition of the business environment

(*continued*)

Table I.

TF family and TF methods	Brief description	Conditions for using TF methods
modelling (CAS) (Chaos) Life cycle analysis		
6. Scenarios Scenarios (scenario management, scenarios with consistency checks) Field anomaly Relaxation method (FAR) Scenario-simulation (interactive scenarios, gaming)	Scenario composing proposes diverse originations of future innovation. Every origination of the innovation is based on a very much characterised arrangement of presumptions. A scene shows the option qualities of the future innovation with every option being given specific suppositions and conditions. The forecaster assesses the legitimacy of the presumptions. The after effects of this assessment are utilised to focus the situation destined to happen (Levary and Han, 1995)	Scenarios are generally used by researchers and admiration to predict the possible as well as preferable future
7. Value/economic/decision methods Action analysis Economic base modelling Cost-benefit analysis Relevance trees (futures wheel) Decision analysis (utility analyses)	Relevance tree approach is the most prominent technique in this family. It is a normative way to deal with TF (Esch, 1972). The different objectives of innovation are separated and arranged in a tree-like arrangement. In this arrangement, the various levelled of the objective of the proposed innovation is formed. Evaluation of the probabilities of accomplishing the objective at the different levels of technological advancement must be done. The probabilities are then utilised to forecast the likelihood of accomplishing the objectives and targets of the innovation which is proposed (Levary and Han, 1995)	Value/economic/decision methods are generally quantitative analysis which is used by the administration in decision making only by considering the financial profit or cost benefit
8. Descriptive and matrices method Back casting Requirements analysis Checklist for impact identification Analogies Innovation system modelling Mitigation analysis Institutional analysis Road mapping Morphological analysis multiple perspectives assessment Social impact assessment Organisational analysis	A developing action in this class is road mapping, which undertakes major technological tasks in manufacturing and product design together for effectively attractive breakthroughs. Roadmaps run an innovation from two to ten years ahead. In a broader term, an innovation roadmap gives a vision or perspective of tomorrow's technologies which is accessible to users. Previously, the institutional champions for road mapping were formed military associations. Now, they have been other expansive partnerships and industry affiliations (Coates *et al.*, 2001) Analogies are likewise prevalent descriptive methods. The utilisation of analogies in forecasting includes an orderly correlation of the innovation to be estimated with some prior innovation that is comparable in all or most vital regards. But as indicated by Firat *et al.* (2008) that "In any case, there is no assurance that people of today will make same choices as individuals did in the prior circumstance. Consequently, the forecast is at most plausible, never certain"	The researchers generally use descriptive and matrices method during the initial design phase of an innovation where researcher try to find the all possible alternative solutions

Observation 3: various TF tools/methodologies may be utilised towards availing vital benefits from TF outcomes regarding valuable predictions and recommendations:

- Expert opinion – it may be utilised for forecasting and innovative improvements by using expertise and experience of specialists in their respective fields. Delphi has been reported as the most prevalent tool to transform subjective opinions into objective recommendations.
- Trend analysis – it utilises the continuation of quantitative past data to predict what is to come and is useful in evaluating the utmost level of technology growth that is followed by a decrease in various phases of technology life cycle and forecasting when innovation is expected to achieve a specific life cycle stage.
- Monitoring and intelligence methods – it may be utilised to predict the lead time and improvements' short-term impacts on acknowledgement and adoption of innovations commercially, and this family include tools such as monitoring variations, environmental scanning, technology watch and resource accessibility.
- Statistical methods – by analysing statistical data to delineate a behavioural pattern of interactions among various variables associated, the most prominent strategies are correlation analysis (for developing patterns to forecast the timing of innovation advancement utilising existing technologies) and bibliometrics (that includes research profiling, patent analysis and text mining).
- Modelling simulation – it may be employed to predict the behaviour of various variables/actors to display the future conduct of complex frameworks helpful in dealing with comprehension of conflict/cooperation between forecast and hidden variables/determinants.
- Scenarios – they may be utilised to propose diverse originations of future innovation based upon well-categorised presumptions' arrangement to assess options' qualities towards focusing on the situation most intended to occur.
- Values/decision/economic methods – these relevance tree approach, which is the most used technique of this family, is a normative way to evaluate probabilities of accomplishing the goals arranged in the form of tree-like levelled structure to predict the likelihood of achieving well-defined objectives of innovation.
- Descriptive and matrices methods – these include innovation road mapping (that takes care of key technological items to predict and provide guidelines for innovations' or products' generations) and analogies (that utilises orderly correlation to estimate with some prior innovation assuming almost similar conditions/ situations).

Furthermore, it is important to mention here that the TF methods are also divided into two categories, i.e. "exploratory" or "normalising". This paper also partitions TF systems into exploratory, normative and the blend of two categories, as per Technology Futures Analysis (2004) Methods Working Group, and the same is also shown in Table II.

Observation 4: all TF tools/methodologies may be categorised into three groups: exploratory (to anticipate the technological state that is likely to be in the future), normalising (to predict and estimate about what technologies need to be or should be conceived at some near future time), and normative/exploratory.

4. Relationships among TF methods

In this segment of paper, we endeavour to evaluate the relationship between exploratory and normative methods that are given in the past literature and try to recognise the linkages

Term	Definition	Characteristics
1. Exploratory	The endeavours to anticipate the technological state that is likely to be in the future	Undertaking foreseen results Recommend distinct options for the proposed allocations
2. Normative	The announcement of what technologies need to be or should be conceived at some near future time REF	Excessively complex and numerically complicated Important when objectives are critical and specific Acknowledgement of monetary possibilities Attention to limitations (normal assets, organisation assets and so on) Acknowledgement of a technological potential
3. Normative/ exploratory	Can be used in two different approaches	They possess the characteristics of both Normative and exploratory

Table II. Categories of TF methods

Sources: Compiled by the authors according to Roberts (1969), Fisher and Pry (1971), Twiss (1984), Martino (2003) and Porter (2010)

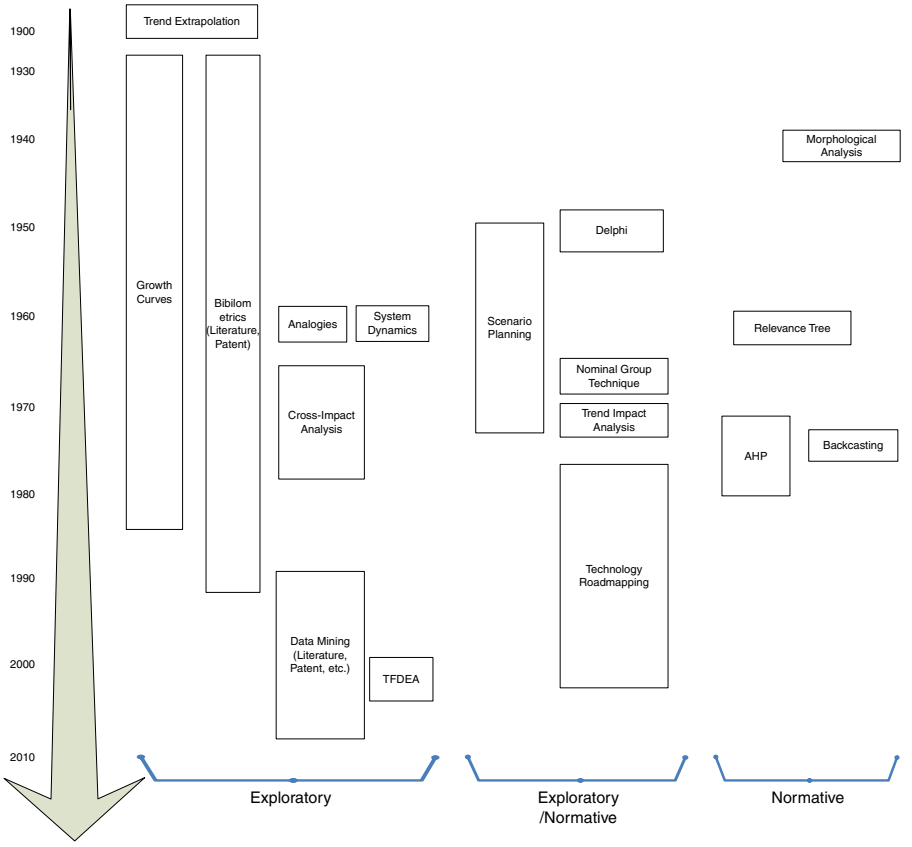
among the methodologies. Some TF strategies are firmly utilising both exploratory and normative methods to anticipate the technological development or changes. Moreover, the choice of fitting TF methods relies upon the nature of the technologies (Mishra *et al.*, 2002). Along these lines, it obliges experience and skill in different TF procedures to choose the suitable estimating models. In fact, this section classifies TF procedures as indicated by exploratory and normative methodologies. Table III demonstrates a lattice of TF methods by sorting strategies and technological characteristics inside every cell, and TF methods are recorded in the decreasing order of their utilisation frequency.

There are no fixed philosophies in technology anticipation or forecasting, and a mix of distinctive methodologies and techniques are generally used to enhance the precision of estimation. Methods hybrids are better than a solitary method (Schnaars, 1989). A blend of different strategies empowers forecasters to examine different points of view (authoritative, innovation, individual, social and natural) (Daim *et al.*, 2006). The specialists in TF contend that the multifaceted nature technologies and quick social change obliged the requirement for developing tools that combine exploratory methods with normative systems (Coates *et al.*, 2001). Over the most recent decades, particularly after the rise of ICT, a percentage of the distinctive methodologies has been developed and utilised by diverse scientists brushing with numerous different tools. Figure 1 exhibits the heritage of TF strategies and also there are some limitations of TF that are systematically analysed and compiled in a tabular form.

Discontinuous		
Bibliometrics (patent analysis, text mining, research profiling)	Trend Impact Analysis	Decision analysis
Cross-impact analysis	Delphi	Morphological analysis
Input–output analysis	Scenario planning	AHP
Diffusion modelling		Relevance tree
Continuous		
Trend extrapolation	Road mapping	Morphological analysis
Growth curve fitting	Trend impact analysis	AHP
Precursor analysis	Delphi	Relevance tree
Long wave analysis	Scenario planning	
System dynamics		
Exploratory	Exploratory/Normative	Normative

Table III. A lattice of TF methods

Source: Adopted from Daim *et al.* (2006)



Source: Adopted from Daim *et al.* (2013)

Figure 1.
The heritage of TF strategies

4.1 Systematic analysis of limitations of TF

A variety of techniques have been developed for technological forecasting. As in all other forecasting methodologies, the most effective ones are based on careful analyses of experience combined with the insights of competent and imaginative people. Each method has its limitations, and we have tried to analyse the limitations of TF systematically. Table IV tabulates the inadequacies of TF techniques.

From this section, we may conclude the following observation.

Observation 5: combination of various tools/methodologies may be used towards effective and efficient forecasting of technology with ample utilisation of information and communication technology for identifying the optimum solution.

5. Technology assessment

The TA concept is more than a quarter century old, and the plethora of research articles is already available in this subject area. However, it is still not clear in the mind of researchers other than its experts. TA is neither simple forecast nor prediction research, or neither social effect analysis nor absolutely system analysis (Finsterbusch, 1980). It deals with the entire system that analyses the effects and the causes (i.e. immediate or

Inadequacies of technology forecasting	
Limitation of quantitative techniques	Exactness, stability and dependability are adversely affected by long-term forecast
	Adaptability to present rate of progress in innovation is troublesome
	Complex models hard to fathom and practice
	The problem in fitting unruly data into the mathematical straight jacket
	Comparative static and reorientation is difficult
	Real-world feedback is difficult to carter
	Lack of adequate past data
Limitation of qualitative techniques (exploratory)	Definition and determination of professional and specialist is troublesome
	Individual inclination goes into a subjective appraisal
	Assigning obligation and responsibility to forecaster is troublesome
	The validity of assumption in situation improvement tends to questionable with time
	Social and political elements are disregarded generally
	Inconsistent assessments and inability to recognise probabilities concerning distinctive timelines in cross-impact
	Number of rounds, nature of expert, precision and dependability has inborn weakness in Delphi
	Sharps interruption of patterns and sudden occasions are evaded normally
	The timescale is either optimistic or pessimistic
	The timescale is not coordinated with innovation
	Forecast confined to inside perspective of the association
	Impingement of other innovations are not considered
Limitation of qualitative techniques (normative)	Dynamics of framework get disregarded in the minuscule vision of innovation
	Maybe connected with passage vision without due respects to the environment
	Technology at the base of the tree may be biased
	Technology choice for the target may fall into a generic category
	Difference between normative and exploratory forecast is often blurred
Difficulties in translating TF into Technology implementation	Commitment is lacking
	Attention to the flexibility of TF in technology implementation is inadequate
	Attention to dynamic tension between exploitative and exploratory activities in an on-going operation. It is thoughtless
	Inadequate to simultaneous rather than sequential development
	Selection of modular technology is neglected
	No attention to dynamics of the impact of technology on organisation
	No critical review and midcourse correction
	Benchmarking and enhance technological performance measurement due to TT is lacking
	Selection of cross-functional team consisting of an expert of TF, TT, engineering, etc., is neglected
	Attention to in-house R&D is inadequate
	TF, TT and implementation are relegated to separate group that experience looping, design looping, and concept crossing are given lesser importance

Table IV.
Inadequacies of technology forecasting techniques

(*continued*)

Inadequacies of technology forecasting	
Human-related problem with forecasters	Selection of the team of the forecaster is not correct
	No-real mean to define an expert who is making a forecast
	The forecasters are not made accountable
	Avoiding criticism, feedback and reorientation for the initial forecast
	Tendencies to prevent information gathering and scanning before the forecast
	Tendencies to resort to immediate gains by incremental developments rather than making radical development as long-term planning
	Individual bias is associated with forecasts and fixing weightings
	Expert block looking at forecast only through one's expertise without considering to parallel developments
	Creative blocks in vision due to social insecurity, fear of consequences, initial and perception factors
	There is a tendency to concentrate on specific configuration rather than considering extrapolating aggregate figure of merit.
	Existence an intellectual rift between forecaster
The problem in selection of technique	There is a mismatch of a technique for the technology to be forecasted
	Overlap of the forecast for continuity is disregarded
	The technique is forced to perceived certain technology
	Validation of technique by another is not carried out to reduce subjectivity
	The technique does not incorporate performance measures

Table IV.

after-effects, sometimes communicated as first-, second- and higher order effects). It finds out whether the effects have been arranged or proposed in true circumstances that are portrayed into technological improvement; furthermore, it explains the advantages or unfavourable nature of the consequences and typically forces investments on a few sections of society that are beneficial.

In an industrialised developed economy, TA may been viewed as an innovation strategy. In developing the economy, TA is viewed as another device for social administration of innovation. TA is relied upon to help in selecting proper advancements for improvement. TA has various views in different economies (Flynn and Bellaby, 2007).

TA generally manages vast and unruly systems that cannot undoubtedly be displayed thoroughly as per the fundamentals of the framework and cannot definitively profit by a great quantitative control of data. Besides, it includes the development and arrangement of choices for economist and decision makers. TA considers the social effects, regarding instability and its consequences, a complete endeavour to study and explore the real issue areas.

5.1 The need for TA

TF methodologies will be important, but not adequate, towards innovation and sustainable development. Thus, we will apply an amplified thought of advancement, which incorporates specialised angle furthermore social and institutional perspectives (Fleischer and Grunwald, 2008). The finding of the general inner conflict of innovation concerning manageable improvement can be changed into a solicitation for sufficient moulding of innovation: innovation and its societal surroundings ought to be produced further and shaped in a manner that its positive outcomes help in economic advancement and negative ones be avoided or minimised.

This is the inspiration for TA: to empower society and to reap the advantages of a particular innovation without running into circumstances of danger for the supportable environment.

5.2 Tools of TA

In writing, there is no specific procedure concerning TA to settle upon. Maybe it is contended that every innovation requires the scope to apply proper methods to a particular circumstance, as opposed to taking after a methodology that is generic (Coates, 1976; Wood, 1997). Also, there is a conceivably different image of TA and its significance that is generally contingent upon the nation and society (Chen, 1979) (Table V).

From this section, we may conclude the following observation.

Observation 6: TA has been recognised as a less revealed and utilised technique to manage vast and unruly systems for assessing long-term consequences of technology to carry out the social administration of innovation for empowering society to reap the advantages of a particular innovation towards sustainable creation/development of the nation.

6. Discussion of findings

It is a fact that the pertinence of TF and TA in today's world is more noteworthy than it was in the past. A lot of assets are piped into innovation systems landed by utilising TFA. In this way, TF and TA impressively have been turn out to be more result-oriented, effective and successful in the present scenarios. The technological change and innovation are both drivers that help in the setting financial, social and political prosperity. Envisioning and comprehending the course of innovative change is problematic for decision makers in both businesses and government organisations. Some techniques are being utilised for TF and TA. Minimal orderly emphasis has been given to the calculated improvement of the TF and TA field overall. With a specific end goal to make TF and TA more powerful, one of the issues that should be tended to is a legitimate choice of the method while accounting its constraints. A conceptual model of TF and TA has been presented in Figure 2, after consulting the experts and reviewing the research text available in various research journals of national and international repute.

6.1 Implications of the research

Examinations of rising advances and their suggestions educate significant choices beginning from the worldwide level to the individual association.

For instance, large organisations need TF and TA, in its different section:

- to prioritise research and development;
- in NPD; and
- in fabricating key decisions on innovation authorising or finding the critical factor that influences the technologies, etc.

Small companies conjointly rely on innovative advancement for their presence. In these companies, TF ways are utilised to gauge appropriation or dissemination of innovation. However, with the exertion to plan financially reasonable guides for technological advancement by organisations, the TF and TA field incorporates or diffuse social estimates too. Apart from this, the study can be used in practice for identifying the method that can analyse the economic, commercial and sustainable outputs. This study can also be used as a teaching material of TF and TA methodologies. Society as a whole is impacted by the TA methodologies as its methodologies help in sustainable development, which influences the public policies. A framework presenting learning, action/s, actor/s and outcomes as deduced from findings of the paper has been put forward in Table VI.

S. No.	Methods of Technology Assessment	Description of Technology Assessment Methods
1	Case study/analysis	Case study analysis includes the "depth examination of past episode to create clarifications that may be generalised to different occasions". Mostly case study analysis is a profundity that supports the different proof of relationships that are causal (Gerring, 2004; George and Bennett, 2005) In this method of technological assessment, there is a case analysis of comparable technologies which gives information about the potential issues that may emerge, nonetheless, where innovation is novel and where similar circumstances are not accessible case study analysis is constrained (Raven *et al.*, 2009)
2	Cost-benefit analysis	A monetary analysis that compares the expenses and advantages, typically evaluated in money-related terms, for situations with and without activity or action (Tran and Daim, 2008)
3	Cost-effectiveness analysis	An economic analysis that gives info about the expense viability of option for accomplishing a goal, and is utilised to find the option with the minimal direct money-related expense (Tran and Daim, 2008)
4	Delphi technique	In the Delphi technique, there is a gathering of individuals (frequently a panel of applicable professionals or experts) who make a judgment and express their suppositions on the given issue. These suppositions are evoked using various rounds of questionnaire or surveys (alluded to iteration) (Rowe and Wright, 1999) with feedback between each round to illuminate the conclusions with the help of their colleagues. This procedure of correspondence is intended to permit a group of people to survey their suppositions in light of the learning of different members (Jain *et al.*, 1993, p. 204). After a few rounds, the last agreement is taken into account the measurable mean/median of the members' conclusions (Rowe and Wright, 1999; Jain *et al.*, 1993). The key components of the Delphi system are the emphasis, anonymity (accomplished with the utilisation of questionnaire) and controlled feedback and also a factual conglomeration of a gathering reaction (Haque *et al.*, 2013)
5	Choice modelling	An experimental strategy utilised as a part of financial matters to edge trade-offs between diverse alternatives. The strategy assesses the estimation of alternatives by uncovering that how much respondents has a will to trade them. Through surveys, data are generally accumulated (Tran and Daim, 2008)
6	Focus groups	A group meeting strategy where a facilitator offers a question to start the conversation among members (Kerr and Tindale, 2011)
7	Impact pathway analysis	It used to anticipate the pathway of effects coming about because of some certain action. This system endeavour to insight into the immediate and backhanded effects of activities and interaction. Otherwise called change pathways (Tran and Daim, 2008)
8	Interviews	A strategy for essential information gathering that comprises top to bottom addressing. The interview may vary as indicated by the sort of informant, the kind of medium (phone or *vis-à-vis*, individual or gathering), and the addressing (organised, semi-organised and unstructured)
9	Input–output analysis	It examines the connections and relationships of output productivity through an examination of the flow of various resources. It is the analysis of the inputs to industry, exchanges between parts, family unit utilisation and the yields of products delivered

(*continued*)

Table V.
List of methods of technology assessment through different categories

S. No.	Methods of Technology Assessment	Description of Technology Assessment Methods
10	Life cycle assessment (LCA)	LCA is a broadly perceived methodology for evaluating the effects of a product or a process over its whole life cycle, and it can apply on any process (Stewart, 1999, 2001; Stewart and Petrie, 2006; Norgate *et al.*, 2007). It has also been utilised as a technique in the assessments of the environment which are for a long period. It is already demonstrated that a frameworks approach (as utilised as a part of LCA) is important in finding open doors for advancement, budgetary funds and development of environmental friendly condition (Bossel, 1999). Over a few years, there is an attempt to include both social and financial components into LCA (Brent and Labuschagne, 2006; Jeswani *et al.*, 2010)
11	Social and regional profiling	A procedure to gather important essential and auxiliary information around a certain section of the community. It helps in profiling an elaborate depiction of the group, environment and economy of a district and gives info about qualities, needs and patterns (Howitt, 1989). It is an evaluation of the present condition of a group or social community which also includes trends. Knowing the certain community helps with envisioning how individuals may react to change (Tran and Daim, 2008). Understanding community includes an investigation of their connections and systems and the qualities that may shape their state of mind and practices. Profiling incorporates examination of demographic patterns, populace attributes, ethnicity and society, the neighbourhood economy, work business sector, area utilisation, social and political association, family and group association, well-being, nourishment, illness, group base and administrations (lodging, well-being, childcare and so forth), group "needs" and wanted fates and the ability to address these issues (Slootweg *et al.*, 2001)
12	Scenario analysis	It is a methodology to acknowledge the change in diverse conceivable future circumstances. Scenario analysis can help to get ready for impromptu planning. On the off chance that directed with groups, scenario analysis can help to educate the general population of risk and helps in managing their goals (Jolly, 2008)
13	Social mapping	A procedure for distinguishing and tracking the importance and qualities credited to a certain area by social communities (Assefa and Frostell, 2007)
14	Consensus conferences	It includes the get together of a chose group of natives to find out around a given innovation and inquiry the technologists on their worries. The procedure ordinarily includes various workshops; with nearly consider 15 natives are taking an interest. These conferences are especially mainstream among European innovation evaluation advocates (Kleinman *et al.*, 2007), it has also been shown some accomplishment inside of an Australia too Einsiedel and Eastlick (2000)
15	Stakeholder analysis	It comprises of selecting of partners; investigation of their fundamental mentality and inspirations, a determination of which partners are most critical, a comprehension of their systems and connections and the improvement and execution of an engagement arrangement (Dewulf and Van Langenhove, 2005). A partner/ stakeholder is any individual who can influence, or is influenced by, an organisation's activities. Focussed on consultation (or centred arrangements) should be created for every partner,

Table V. (*continued*)

S. No.	Methods of Technology Assessment	Description of Technology Assessment Methods
		particularly for a vulnerable group. Partners have changing degrees of force, authenticity and enthusiasm for an issue or a venture. Partners additionally incorporate individuals inside of organisations that may be imperative to the arranging, improvement and execution of the action (Hoffmann *et al.*, 2004)
16	Strategic and regional assessments	It may be embraced during or before establishing a new kind of organisation. The upside of such methodologies is that they: encourage the early recognisable proof and determination of potential issues when there is the adaptability to roll out improvements, give a chance to longitudinal and comparable examination(Stewart and Petrie, 2006). It helps in more successfully recognise existing and potential aggregate effects, might expressly connect evaluation to provincial arranging and reporting and can set up the standard and territorial data sets that help the improvement of area wise checking endeavours. It can be the most proper type of evaluation for different regions including multiple partners and have large scale activities (Evans *et al.*, 2007)
17	Sustainability assessment and metrics	In sustainability assessment, there is a term that covers a large scope of approaches with no specific set of methodology. It inspects an innovation, technologies or processes in the light of economic advancement criteria or measurements, an endeavour to recognise changes or effects on ecological, social and financial bases (Khurana *et al.*, 2014). Physical sciences methodologies have a tendency to command sustainability assessment, particularly as to innovation appraisal where numerical methodologies are frequently looked to give some apparent elevated amount of assurance than subjective depictions (Jischa, 1998; Azapagic, 2004; Hoffmann *et al.*, 2004; Dewulf and Van Langenhove, 2005; Pinter, GRI, 2006)
18	Trend analysis	The accumulation and examination of verifiable and contemporary information to illuminate the forecast of future (Tran and Daim, 2008)

Table V.

6.2 Unique contributions of the research

TF and TA have been the developing area of management studies for decades (Nikolopoulos *et al.*, 2015). Some studies on TF and TA have been reported in the past and have helped in the development and advancement of this field. However, there is no endeavour made to introduce a compiled review of the methodologies and its tools that have been referred to TF and TA (Altuntas *et al.*, 2015). In this study, we try to fill that void. An intensive audit of the TF and TA from the past studies is led to the exploration of different tools and methodologies towards providing the following observations.

- Experts' opinions are important to transform subjective opinions into objective recommendations towards carrying out forecasting and innovative improvements.
- To predict future, trend analysis utilises continuation of quantitative past data, whereas, monitoring and intelligence methods are being utilised to predict short-term impacts.
- Statistical data and its analysis are used to delineate a behavioural pattern of interactions among various variables associated; also, modelling simulation can be

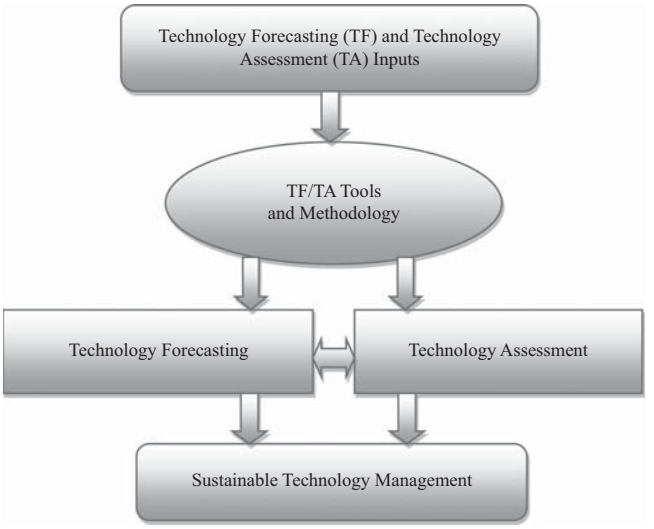


Figure 2.
A conceptual model of technology forecasting and technology assessment

found useful to predict the behaviour of various variables/actors to deal with conflict/cooperation between forecast and hidden determinants.

- Scenarios may be utilised to propose different originations of future innovation-based presumptions' arrangement; however, the relevance tree approach (one of values/decision/economic methods) uses probabilities of accomplishing the goals. Also, descriptive and matrix methods include innovation road mapping and analogies.
- TF tools/methodologies may be categorised into three groups: exploratory, normalising and normative/exploratory; however, a combination of various tools/methodologies can be a good option towards effective and efficient TF with ample ICT utilisation.
- Furthermore, TA has been observed as a less revealed and utilised technique to manage vast and unruly systems.

The paper may be helpful in selecting the appropriate method of TF and TA for a specific situation. An exhaustive presentation of the methodologies/tools has been introduced.

7. Conclusion

We should refrain from considering forecasting and assessment as a solitary action with "one size fits all" philosophy. This study concludes that the quest for a single strategy for doing forecast and assessment is a misconception because this neglects to perceive that forecast and assessment oblige a suitable blend of strategies and methods drawn from a variety of fields. The proper blend of techniques to be utilised, the variables to be chosen, the units of estimation to be utilised and the grouping of analysis must remain a function of the problem in hand and the experience and inventive, creative ability of the investigator(s).

This study is an in-depth literature review of TF and TA using the paper mainly available from 1960 to 2015. This study is more general in application, for future research, one can study more industry specific or problem specific. Furthermore, one can also include the different factors that can lead to the selection of a particular methodology.

Observation	Learning	Action/s	Actor/s	Outcome/s
Observation 1: TF and TA needs to be explored regarding tools/ methodologies	Research efforts need to be fostered in TF and TA area	Initiation and actualisation of research programs at fast track	Researchers, research organisations, academicians, universities	Research findings
Observation 2: not ample literature available on TF and TA tools/ methodologies relevant to new product development (NPD)	The literature on TF and TA to be made available relevant to new product development (NPD)	Organising conferences, seminars, workshops, etc.	Researchers, research organisations, academicians, universities	Developing countries' relevant literature
Observation 3(a): expert opinion may be utilised for forecasting and innovative improvements to transform subjective opinions into objective recommendations	Utilising expertise and experience of specialists has been found vital to transforming subjective opinions into objective recommendations	Identifying specialists/ experts of relevance from diverse disciplines; contacting them and arranging for the appropriate conducive environment for interactions (direct/ indirect)	Specialists/experts, organising crew	Valuable recommendations
Observation 3(b): trend analysis utilises continuation of quantitative past data to predict future	Quantitative past data may be utilised towards TF	Identifying relevant past data; sorting and correcting data to make it usable for trend analysis; arranging for appropriate software and skilled professional; carrying out trend analysis	Data mining organisation/experts, IT professional/s, Trend analyst/s	Utmost level of technology growth that is followed by a decrease in various phases of technology life cycle and forecasting when innovation is expected to achieve a specific life cycle stage
Observation 3(c): monitoring and intelligence methods may be utilised to predict short-term impacts and tools are monitoring variations, environmental scanning, technology watch and resource accessibility	Monitoring and intelligence methods may be useful to forecast short-term gains in commercial terms	Keeping a close watch on technological changes, developments and innovations nationally and globally and their impacts on various stakeholders/ nation/country's counterpart	Monitoring and intelligence methods' experts	Lead time and improvements' short-term impacts on acknowledgement and adoption of innovations commercially
Observation 3(d): by analysing statistical data to delineate a behavioural pattern of interactions among various variables associated, and the most used strategies are correlation analysis and bibliometrics	Statistical data availability may be followed by statistical analysis for authentic forecasts and predictions	Making suitable data available, apply statistical tests for its analysis towards making forecasts	Statistical analysis experts/specialists, IT expert/s, TF expert/s	Behavioural pattern of interactions among various variables associated; most acceptable recommendations based upon statistical forecasts
Observation 3(e): modelling simulation may be utilised to predict the behaviour of various variables/actors helpful in dealing with conflict/ cooperation between forecast and hidden determinants	Simulation and modelling may reveal hidden determinants' behaviour that further makes decision making effective and reliable	Identifying variables/ actors, arranging for suitable data and modelling/simulation software, carrying out simulation/modelling, analysing results	Firms/individuals making suitable data availability, simulation expert/s, IT expert/s	The behaviour of various variables/ actors to display future conduct of complex frameworks

(*continued*)

Table VI.
Learning and actions

Observation	Learning	Action/s	Actor/s	Outcome/s
Observation 3(f): scenarios may be utilised to propose diverse originations of future innovation based upon well-categorised presumptions' arrangement to assess options' qualities towards focusing on a situation most intended to occur	Diverse originations of future innovation may be predicted by using scenario technique	Identifying/finalising presumptions, identifying options and their qualities, carrying out the assessment of options for a situation most likely to happen	Scenario experts	Assessment of qualities of alternatives/options
Observation 3(g): value/ decision/economic methods- relevance tree approach, which is the most used technique of values/decision/economic methods' family, showing probabilities of accomplishing the goals arranged in the form of tree-like structure to predict the likelihood of achieving objectives of innovation	Probabilities of accomplishment of various objectives of innovation/s may be evaluated using a relevance tree approach which may further facilitate to make recommendations/ decisions	Defining the problem, arranging probabilities of accomplishing the goals arranged in the form of tree-like structure, analysing the probabilities' structure, making predictions	Relevance tree expert/s, technology forecasting specialist/s, mathematician (expert in mathematical operations on probabilities)	Probabilities of goals accomplished in the form of levelled structure, forecast exhibiting a likelihood of achieving well-defined objectives of innovation
Observation 3(h): descriptive and matrices methods include innovation road mapping and analogies	Long-term TF and planning may be done by using this category of TF	Gathering relevant facts and figures, preparing innovation roadmaps/analogies towards log terms predictions	Highly experienced and skilled TF experts	Technology/ innovation roadmap/ s, long-term guidelines for innovations' or products' generations, analogies
Observation 4: all TF tools/ methodologies may be categorised into three groups: exploratory (to anticipate the technological state that is likely to be in the future), normalising (to predict and estimate about what need to be conceivable at some future time) and normative/ exploratory	A clear understanding of three categories of TF tools need to be developed, every category has its advantages and limitations	Developing a clear understanding of TF tools and their respective category, developing a clear understanding of TF tools' relative advantages, disadvantages and applications	TF expert/s	Better understanding and facilitation of choice making of TF tools from three categories depending upon nature of problem/ situation/technology
Observation 5: combination of various tools/methodologies may be used towards effective and efficient TF with ample ICT utilisation	Different TF tools may be combined towards achieving hybrid methodology o overcome limitation/s of tools when used individually	Evaluating various combinations of TA tools regarding their advantages and limitations	Specialists/experts	Hybrid TF methodology for optimum solution
Observation 6: TA has been recognised as less revealed and utilised technique to manage vast and unruly systems	TA tools need to be appropriately analysed and utilised	Assessing long-term consequences of technology, social administration of innovation for empowering society	Government, international organisations, TA specialists/experts, data mining experts/firms; Stakeholders, general public	Sustainable creation/ development of the nation

Table VI.

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