Technological Impact Assessment: A Framework for Designing a TIA Project Method

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***Abstract*—Technology Assessment (TA) is a term of long standing for a process that examines consequences of the application of a particular technology. The scope and scale of technological impacts have greatly increased over the last six decades; but TA has ossified. An alternative term, Technological Impact Assessment (TIA), is used for processes that adopt broad, open and balanced approaches. TIA is far more challenging than other related techniques, such as the financial evaluation of proposed projects, privacy impact assessment, regulatory impact assessment and even environmental impact assessment. The enormous diversity of technologies, cultural contexts and drivers makes it infeasible to specify a generic project method that will serve all needs. This article identifies and discusses the key dimensions of those challenges. A framework is presented that is designed to support those who plan and conduct TIAs of all kinds. A simple worked example is provided.**

***Index Terms*—Technology assessment, consequences, risk management, socio-technical systems.**

I. Introduction

IN THE post-industrial era, new technologies are leveraging off a very strong and complex infrastructural base. This is resulting in greater rapidity of innovation, and even less transparency than has existed in the past. Information about new technologies emerges too slowly to enable public evaluation of the features. Many of them are complex, and their operation obscure, by their nature and in some cases by intent. Impactful technologies generate benefits. On the other hand, negative consequences are likely to be much more substantial, to be hidden from view, and to fall inequitably on the less powerful and the socio-economically disadvantaged [68; 69, pp. 688-670]. The importance of early assessment of new technologies is therefore even greater than it has been in the past.

This article adopts the following set of terms for several categories of technological effect. Their boundaries may not be clear-cut, but they assist analysis:

- ‘consequences’ is used as the generic, non-judgmental term for effects of all kinds, encompassing economic, psycho-social, political and environmental aspects;
- ‘benefits’ is used for positive effects;
- ‘impacts’ is used for direct negative effects;
- ‘implications’ is used for indirect negative effects; and
- ‘risks’ is used for contingent negative effects.

Various kinds of impact assessment techniques exist. Corporations prepare business cases for projects they are considering, and evaluate their prospects using net present value calculations and risk assessments. Government agencies conduct cost-benefit analyses. Large scale developments such as mines and large-scale transport infrastructure projects are subject to environmental impact assessments. Parliaments protect industries by conducting regulatory compliance impact assessments. Effects on social values are considered in privacy impact assessments and human rights impact assessments. This article is concerned with a category of assessment technique that has been referred to for at least the last 50 years as technology assessment (TA). TA’s origins and purposes are discussed, and references to seminal articles are provided, in Supplementary Paper 1 to this article.

Rather than being limited to a particular intervention into a particular context, TA relates to a technology that may be applied in many contexts or as part of a wide range of interventions. Many stakeholders, values and value-sets may be in play. TA has been practised largely by specialist agencies reporting to a particular jurisdiction’s parliament or government. In Supplementary Paper 1 to this article, a brief history of TA is provided, as practised initially by a specialist US government agency, the Office of Technology Assessment (OTA) [28], [55], and on an ongoing basis by government agencies, primarily in of European countries [34]. It notes how the technique has degraded over its 50-year history, with narrowed focus, minimal public engagement, and strong emphasis on economic development and other positive impacts, and with less attention paid to negative impacts, implications and risks. A recent collection of case studies of TAs is in [40].

In this article, the term Technological Impact Assessment (TIA) is used. This has a similar nature to TA, but leaves open the question as to what entity performs it and who the primary audience is intended to be. It also places stronger emphasis on wide engagement and on recognition of harmful impacts.

This article is motivated by the enormous impacts of many advanced and emerging technologies on human values, and the need for much more attention to be paid to them, and at earlier stages in technology life-cycles. The article’s purpose is to present a framework for process design for TIAs of all kinds. Its contribution is conceptual and methodological.

A TIA Framework (TIAF) is an abstract socio-technical artefact presenting a palette that can be used to generate project plans of many different kinds, depending on the choices made in relation to a defined set of elements. The

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methodological approach that has been adopted applies well-established guidance in relation to design science, which is applicable to the development of such a socio-technical artefact [53; 40, p. 337]. The process adopted reflects Peffers' Design Science Research Methodology (DSRM) [56]. This distinguishes steps for problem identification and definition of objectives, followed by design and development, and demonstration, and then evaluation, and communication.

In Section II, a working definition for TIA is defined, and a set of a dozen elements is proposed that need to be considered when developing a project plan for assessing the consequences of any particular technology. In Section III, each of those elements is discussed, drawing attention to the salient aspects that are relevant to the establishment of an effective project plan for each particular PIA. In Section IV, access is provided to an Appendix that demonstrates the application of the framework to create a tenable project plan for a simplistic instance of a TIA.

II. Background

The origins and history of TA are presented in Supplementary Paper 1. TA emerged within a specialist US government agency 1972-95, with the tradition since maintained in some European countries. However, its once broad scope has been trimmed, and the openness of the processes debased. Its impact on policy decisions has also been muted. In recent years, momentum has been emerging from efforts of researchers, civil society, and consultancy groups attuned to the seriousness of the impacts and implications of powerful technologies and over-exuberant endeavours to apply them. To reflect the changed context, the term TA is used in this paper specifically for the now-narrow approaches within government, and TIA is applied to the contemporary approach.

Drawing on the earlier definitions of TA in Supplementary Paper 1, the working definition of a TIA used in this work is as follows:

> A Technological Impact Assessment is an examination of economic, psycho-social, political and environmental consequences of one or more particular applications of a particular technology, in one or more particular contexts, in order to provide guidance to policy makers on likely benefits, impacts, implications and contingent risks, and to thereby lay the groundwork for the consideration of policy alternatives.

Literature searches uncovered only a modest number of academic publications that contribute to the specific objectives of the present article. For example, [48] consolidates workshop participant's views on 'constructive TA' in developing countries. It is clear, however, that each particular TIA, at the outset, needs to establish sufficient clarity about its purpose, context, and intended deliverables, and develop, articulate and implement a project design that features task specification, scheduling, resource planning, implementation, planning, control, flexibility, and scope for adaptation as the project proceeds.

The US OTA's approach to TA method evidenced an endeavor to impose structure and rigor, while retaining sufficient flexibility to cope with the diversity of technologies the agency examined [28]. Approaches used by the US Government Accountability Office (GAO) [37] and the Organization for Economic Co-operation and Development (OECD) subsequently narrowed the catchment area to primarily technocratic sources, the scope to primarily economic objectives, and the role of the public, and of advocates for its interests, largely to that of a target audience to be educated and reduced to blind trust of authority. An effective TIA project method demands more open conception.

In [10], [11], the authors argue that systematic literature review needs a constructively loose and iterative process. Their process model accordingly embodies loops both of literature search and acquisition, and of analysis and interpretation. This avoids undue constraints, unlocks insight and creativity, and enables emergent and changing understanding of relevant phenomena, and adaptability of the research question itself. This author's contention is that TIA project method needs to exhibit similar looseness and inbuilt iterations.

TABLE I
Elements of the TIA Process Design Framework (TIAF)

Framing	1	Purpose of the TIA
	2	The Technology
Factors	3	Stakeholder Analysis
	4	Socio-Technical Analysis
	5	Socio-Political Analysis
	6	Possible Trajectories
	7	Domains of Application
	8	Cultural Analysis
Features	9	Deliverables of the TIA
	10	*Modus Operandi* for the TIA
	11	Research Techniques
	12	Policy Analysis

III. The TIA Process Design Framework

TIAs evidence enormous diversity. Each naturally reflects the particular technology in focus. In addition, each is conducted within a rich context. As a result, no single approach or template can be put forward. The purpose of this paper is to provide a TIA Framework (TIAF) within which a project design can be developed for each particular technology and context. A set of contextual elements is identified in Table I.

The following sections present overviews of each element, identifying relevant considerations, and suggesting alternatives that may be appropriate choices depending on the circumstances. The framework provides a checklist of aspects that project leaders may need to factor into their own analyses. Sections IV–VI provides discussions of each of the elements in the Framework clustered into three parts, framing, factors and features, as outlined in Table I.

IV. Framing

A. Purpose of the TIA

In some circumstances, a TIA project commences with a pre-defined Terms of Reference, which specifies the purpose, and most likely guides interpretations of some of the further elements below. In other cases, project leaders may have only an informal impression of the scope and intentions, and a purpose may need to be postulated and then iteratively adapted and refined as the further elements below are considered. Depending on the circumstances, **preliminary project-work** may need to be conducted prior to the purpose being formulated, in particular the gathering of sufficient information about:

- The relevant technology/ies;
- Application ideas, pilots, trials and pioneering projects;
- Critiques of the technology/ies; and
- The social, political and policy context(s).

Beyond literature reviews, such preliminary work may need to extend to consultations, discussions, and possibly surveys or focus groups.

The following key factors need to be taken into account in formulating the definition of purpose:

- **The institutional context**. This may involve a specific organizational host, a joint venture or other bi- or multi-lateral arrangement, or a fluid association among participants, with more or less open boundaries;
- **The vehicle** for the conduct of the project. This may be:
  - a formally constituted entity, or part of one, or an *ad hoc* association;
  - a standing organization or single-project task force;
  - a contract for the performance of a service;
- **The target audience(s)** for deliverables. This may be, or may include, one or more Parliaments or governments; a specific policy agency; an entity that commissioned the TIA; industry, professional or civil society associations; and/or the public generally;
- **The available resourcing**, in cash and kind, and the scope for that to be supplemented;
- **The time-horizon(s)** within which deliverables will desirably be produced; and
- **The available support**. This may be of an infrastructural nature, or prior research reports of general relevance to the topic or specific relevance to the purpose, or expertise in aspects of the subject-matter

Given the complexities of a TIA process, as discussed throughout this section, it is in principle highly desirable for the definition of purpose to be negotiable, flexible and adaptable, to reflect what is learnt during the early stages of the work. The extent to which those attributes can be achieved is of course dependent on real-world constraints.

The next element, which looms particularly large during the preliminary work, is of course the technology to be studied.

B. The Technology

Careful definition is needed of **the scope of the technology** whose consequences are to be investigated. The term 'technology' is used here in the sense of "any product of knowledge dealing with the mechanical arts and applied sciences that is of practical application" (OED 4a-c). A variety of sources provide indications of potentially useful clusterings of technologies (e.g., [4], [29] and the Wikipedia List of Emerging Technologies). Reference [29] includes a potentially valuable categorization, and a sub-list of "enabling" or infrastructural technologies.

The term 'technology' can be used at varying levels of abstraction, at one extreme, and granularity, at the other. For example, electricity-generation technology may be from:

- carbon-based sources -- and at a more granular level, anthracite, brown coal, gas, or fracking;
- 'green' or renewable sources -- hydro, sunshine, wind, tides; or
- nuclear sources -- fission, fusion.

Some attributes may be common across multiple categories (e.g., all carbon-based sources generate harmful gaseous emissions). On the other hand, each category has very specific characteristics that give rise to its positive and negative consequences, and hence needs consideration independently of other, related categories.

In addition, sufficient **depth of understanding** of the technology is essential, to ensure that the features relevant to its consequences can be identified, and policy analyses can thereby be grounded rather than superficial. Analysts also need to consider that some technologies have features that inherently bias the outcomes in directions favoring some stakeholders or values over others, and some are custom-designed to do so [66]. This understanding is not only needed by the team performing the TIA. It also needs to be conveyed, in short but accessible and reliable form, to the audiences to which the assessment is addressed.

A crucial pre-condition for an effective TIA is the identification and appreciation of **the key features of the technology that give rise to opportunities and threats**, and that therefore need close attention throughout the analysis.

A preliminary understanding may need to be achieved of these aspects of the technology, and the topics may need to be revisited iteratively both as this framework's 10 elements are considered during the project initiation phase, and as the project is pursued. In the meantime, the next important element is clarification of what parties are affected by, and are likely to care about, possible positive and negative consequences of the technology's adoption.

V. Factors

A. Stakeholder Analysis

Stakeholder theory provides valuable guidance in relation to the identification and evaluation of categories of parties that have an interest in the nature, applications and consequences of a new technology. The concept arose within management theory, and was created to provide a counterpoint to 'shareholders', whose interests are directly served by the legal framework created by corporate law [36].

The stakeholder notion has been applied not only in business enterprises, but across all organizational contexts. Entities are readily recognized as stakeholders when they are **participants** in a system, or **users** of information systems. A vital category that organizations commonly overlook, however, is entities that are affected by the behavior of a system even though not participants in it. This may be because they are merely objects that are impacted by it, or second-order implications affect them, or they bear the costs of contingent risks. The term '**usees**' has been applied since at least 1990 to refer to those categories of stakeholder [8, p. 388, 19, 36, 6].

Stakeholder salience theory identified three key stakeholder attributes: power, legitimacy and urgency [47], [51]. Reference [31] later proposed the addition of proximity. Sponsoring organizations commonly consider only those **stakeholders with sufficient power** to affect project success, with the interests of legitimate-but-not-powerful stakeholders perceived at best as constraints on the achievement of the sponsor's objectives.

An important consideration in the case of stakeholder categories with many members is the allocation of entities into **groups or segments.** In addition to human and organizational entities, it has become mainstream to recognize **abstract stakeholders**. Important examples are community, society, economy, polity, and environment in the sense of biosphere or nature [31], [42]. The difficulties of achieving stakeholder engagement in the development of technology is mirrored in the experiences of research funding bodies seeking to implement Responsible Research and Innovation (RRI) policies [9].

For stakeholder categories that comprise large numbers of entities, and for abstract stakeholders, it is necessary to use **stakeholder proxies** in order to gain access to insight into stakeholders' interests and attitudes to particular technologies and their features. The closest approximations are generally advocacy organizations (such as large membership-based consumer organizations) and competency-based organizations that specialize in particular areas, such as Environmental Defenders Offices, privacy and digital rights associations, and civil liberties councils.

A further important insight is provided by **researcher perspective** theory [27]. A large proportion of academic research, particularly in business disciplines, adopts the perspective of a single entity, and a large proportion of that is dedicated to the interests of the sponsor of technologically-based interventions. Dual-perspective research can reflect, in particular, both system-sponsor and user views, and inter-relate them, to the benefit of both; yet it is uncommon. Most relevantly for the present purpose, **multi-perspective research** is very challenging, and hence less common in academic research.

Recognition of the significance of stakeholders leads naturally to the need for a more expansive view of technology, as technology-in-use.

B. Socio-Technical Analysis

Earlier sub-sections have considered the features of the technology and stakeholders' interests. The socio-technical systems approach provides ways in which inter-relationships between the two can be brought into focus [1], [3], [17], [33], [49]. Fundamental to the approach is recognition that the assumption that a singular 'truth' exists is inconsistent with the existence of **multiple perspectives, interests and value-sets**, and that different stakeholders interpret technical phenomena in different ways.

Further, the differences among stakeholder interests are likely to be significant, such that **conflict** exists among different stakeholders' interests, and **competitive behaviors** occur as the various stakeholders seek to advance their own interests. As a result, in contexts of any complexity, balance and compromise are difficult to achieve. The TIA process generally needs to make comparisons between factors that cannot be measured on the same scale.

Socio-technical thinking emerged in the period of intra-organizational systems, but is also applicable to **inter-organizational systems** that involve individuals operating within multiple organizational contexts [1], and **extra-organizational systems**, which involve or affect individuals beyond organizations' boundaries [18]. Critical aspects of effective technological design include the capacity of affected individuals to not only be aware of the design intentions, but also to influence the design and operation of the technology and its applications. This depends on **participative and consultative arrangements**, on **flexibility** to recognize and deal with variations and exceptions, and on **adaptability** to cope with changes both environmental and social in nature.

An important element within the socio-technical space is the distinction between a feature and an affordance. From the technical perspective, **features** of a system are designed-in, with the intention of providing particular capabilities. From the psychosocial perspective, on the other hand, **affordances** are potential or emergent properties of a system that individuals discover or perceive, or perhaps appropriate, contrive or subvert. A novelist's graphic depiction of the notion is "the street finds its own uses for things" [37].

A TIA process needs to have its sights set well beyond technical design of artefact features, encompassing **the psychology and psychopathology of artefact use** [53]. In the IT context, design frameworks such as human-computer interface (HCI), and its contemporary conception as user interface (UI) and user experience (UX), need to be conducted in an open-minded manner [44], and extended to usee or non-participant experience (NPX). The next sub-section moves beyond the interactions between technology and society to consider socio-technical systems' interactions with the polity.

C. Socio-Political Analysis

In some contexts, **the power of one or more particular stakeholders** weighs very heavily in decision-making about whether and how technology may be applied. **Institutional power** may be exerted, particularly by governments and government agencies. **Market power** may be exercised by large corporations and industry associations.

The long-apparent drift from subcontracting, via comprehensive outsourcing, to public-private partnerships, and on towards **the corporatized state**, gives rise to linkage and cross-leveraging between the two types of power [60]. In that context, particularly in the USA and in countries that follow its lead, such TAs as may be performed by government agencies are likely to be wholly benefits-oriented, without even OECD-style concessions in such areas as nominal participation in standards-setting, and trustworthiness as a goal for technology and its providers.

The design of effective TIA processes needs to embrace the full breadth of the original notion of TA, rather than its contemporary, debased form. On the other hand, project leaders need to appreciate that the products of the TIA process may be injected into a world hostile to objectives beyond the economic aims of the corporatized state, and policy contributions may have to be navigated through the moral morass of a 'post-truth' world.

With the social and political factors relevant to a TIA now delineated, two further aspects of the technology under study need to be considered.

D. Possible Trajectories

Although each technology follows its own path of development, some commonalities can be identified. Models exist that assist in analyzing the possible paths that the technology under study might follow.

A starting-point is to establish **a baseline description of the technology** as it is understood at the commencement of the study. This exercise may encounter challenges. One is the novelty and perhaps foreignness of the technology and the terminology used to explain and promote it. Another is vagueness about its nature and features. This can extend to secrecy justified by desire on the parts of the inventor and innovators to be able to exploit their ideas commercially. Obstructionism may also arise where the claims made for the technology are exaggerated, baseless or fraudulent.

A further important aspect is the technology's **stage of maturity within the technological life-cycle**. The Gartner consultancy group's populist 'hype cycle for technology' postulates five key phases, beginning with a 'technology trigger', a period of 'inflated expectations', followed by a trough of 'disillusionment', leading to a slope of 'enlightenment', and ultimately a plateau of 'productivity'. Case studies of the first three phases may provide insights into patterns of behavior relevant to the technology under study.

Caution is expressed by some, about the Gartner cycle, and about strongly-hyped technologies: "Tracing breakthrough technologies over time, only a small share -- maybe a fifth -- move from innovation to excitement to despondency to widespread adoption. Lots of tech becomes widely used without such a rollercoaster ride. Others go from boom to bust, but do not come back. . . . An alarming number of technology trends are flashes in the pan" [32].

A considerable academic literature exists in relation to lifecycles for manufactured products, but the body of theory at the more abstract level of technology life-cycles is more limited. In the case of **new, substitutive technologies** (e.g., engine propulsion mechanisms, or music recording technologies), a useful review article is [64]. It summarizes the process in such cases as comprising a succession of 'paradigms' (e.g., steam, petrol, diesel, hybrid, electric; or vinyl records, magnetic tape, optical disk, solid-state digital storage), each of which passes through stages the authors refer to as an 'era of ferment', 'emergence of dominant design'; and an 'era of incremental change'; with sub-stages they refer to as 'generations'. Successive paradigms are separated by 'discontinuities' ([64, pp. 550–551, Fig. 6]). Reference [65, p. 22] proposes a somewhat different notion of 'architectural' technologies, relying on "a new configuration of (existing) technologies, resulting in at least partially novel functionality."

That model is not applicable to what might be termed **'emergent' or 'emerging' technologies**. Nano-technology, successive waves of genetic technologies, and perhaps quantum technologies may create new areas of application. In that case, there is no predecessor paradigm that acts as a reference-point and that needs to be overrun or subsumed. These are more thorough 'shifts', or 'discontinuities' in that term's more common sense of redefinition of the space, throwing into doubt previous assumptions and graphical projections. In [65], these are referred to as '**radical**' technologies. The TIA framework is proposed as being applicable to both substitutive and emergent technologies.

In [58], the defining attributes of an 'emerging technology' are proposed. The first, "**radical novelty**", embodies the discontinuity notion. However, the other four (fast growth, coherence, prominent impact, and uncertainty and ambiguity) appear not to qualify as definitional. Moreover, the important definitional feature of '**immaturity**' is missing. ("Uncertainty and ambiguity" are attributes that derive from immaturity). As regards impact, prominence cannot yet be judged, and some term such as '**apparent (and/or claimed) impactfulness**' would be more appropriate. That factor affects the technology's interestingness to researchers and investors, and its potential relevance to technological impact assessors. That, and **the rate of accretion of knowledge** and the **coherence of the propositions**, are relevant factors in gauging the technology's maturation trajectory, and likelihood of progressing through the technology lifecycle.

Also, of relevance is the **technology adoption life-cycle**. For example, Rogers' widely-adopted theory of diffusion of innovation [57] contends that the important characteristics of an innovation that influence its adoption are:

- **Relative advantage** (the degree to which it is perceived to be better than what it supersedes);
- **Compatibility** (consistency with existing values, past experiences and needs);
- **Complexity** (difficulty of understanding and use);
- **Trialability** (the degree to which it can be experimented with on a limited basis); and
- **Observability** (the visibility of its results).

Diffusion of innovation theory includes many ideas on pioneer and early-adopter patterns. These are likely to affect the directions in which the technology is articulated, and may provide insights into the adoption lag, and the degree of steepness of the adoption curve.

In deliberating about possible trajectories that the technology under study may follow, it is important to distinguish between:

- **Claims, projections and predictions** by inventors, investors and enthusiasts;
- **Prognostications** by less self-interested and more circumspect observers;
- **Recognized patterns** (including both academically respectable and populist models); and
- **Unforeseen paths** arising from features and adopters that were not originally emphasized, and from spin-offs from the core technology.

The following section considers the related question of the fields to which the technology is applied.

E. Domains of Application

Some technologies have a very specific purpose, within a specific field. Other technologies begin with a narrow purpose, but one or more further areas of application are found (as occurs with some pharmaceuticals, later discovered to have beneficial effects for additional medical conditions). Yet others, however, such as steam, spark-ignition, compression-ignition and rotary engines, have a great many domains of use.

As with the technology itself, at the commencement of the study it is valuable to establish **a baseline description of applications** for which the technology was conceived and designed, and/or at which the technology has been targeted. Similarly, it may be useful to distinguish claims about the domains of application by inventors, investors and enthusiasts, from those of soberer and less self-interested commentators, and to allow for the possibility of redirection of effort towards, or adoption in, additional or alternative domains that may or may not have been foreseen.

Building on the consideration of foundational techno-social factors in an earlier sub-section, there is a need to consider a further, more abstract aspect of the societies into which technologically-based interventions are inserted.

F. Cultural Analysis

The term 'culture' is used here to refer to "the distinctive ideas, customs, social behaviour, products, or way of life of a particular nation, society, people, or period" (OED III.7.a). Culture could be regarded as merely a higher level of abstraction. However, a culture is both more pervasive and deeper than common-interest groupings. The interests of people who identify with a culture are often embedded in **value-sets** that have considerable persistence over time. A longstanding categorization of aspects of culture is in [62], and is combined with an ideological dimension in [59].

In many countries, a **dominant culture** exists, variously complemented and challenged by **minority cultures**. Cultures are in most cases delineated along racial / lingual / religious lines, and are sometimes regionally concentrated, although some, such as 'hippie culture', have arisen as reactions against a dominant culture. In some cases, a TIA will accordingly need to take account of the value-set of a dominant culture, and in most cases some degree of recognition of the notions of **cultural diversity** will be necessary.

Many cultures evidence **conservative attitudes** towards some aspects of social behavior, and this can result in conflicts with particular technologies. This is commonly the case with technologies that interfere or interact with human biology, or with animal or plant biology, or that grant degrees of autonomy to artefacts, particularly where the actions taken by artefacts directly affect humans. Conservative attitudes are also commonly evident in cultures that lie towards one end of the theocratic-secular and authoritarian-democratic dimensions.

The contentiousness of some technologies may 'fly beneath the social radar'. For example, cyber-physical technologies such as industrial control, supervisory control and data acquisition (SCADA), 'fly-by-wire' in aircraft and cars, and the emergent smart grid, are hidden from view and offend few people. Those examples can be contrasted with driverless cars, and the sophisticated prostheses and orthoses that underlie cyborgization [20], [21]. These are more likely to trigger controversy by being perceived to conflict with the prevailing social values of a dominant culture, or even of a vociferous minority culture.

Analyses may rely on racial / lingual / religious cultural foundations. Another alternative is to evaluate consequences on the basis of where on particular **cultural dimensions** a country, or a country's dominant culture, is seen to lie. A well-established model to support such analyses is the Hofstede/Minkov Dimensions of Culture (formally described in [46]), which in its current form identifies six dimensions:

- Power distance index
- Individualism vs. collectivism
- Uncertainty avoidance
- Motivation towards achievement and success (cf. masculinity and femininity)
- Long-term vs. short-term orientation
- Indulgence vs. restraint

To this point, this section has worked through the framing of a TIA, and factors affecting the project plan. The remaining sub-sections consider features of the TIA process.

VI. Features

A. Deliverables of the TIA

TIA is a process. Some payback from that process is likely to arise from changes in insights and attitudes among participants. Under some circumstances, TIA activities may extend to experimental design and pilot implementations. However, in order to influence and perhaps even drive outcomes, it is usually necessary to have some degree of focus on products. A tome containing a summary, a report body and appendices may be required, but that may be primarily of symbolic value, a historical record, or a contribution to the literature. More direct contributions are likely to arise from shorter, accessible documents relating to such matters as:

- **The Technology** and its features, and perhaps affordances, that are relevant to impact assessment;
- **Potential Technological Trajectories and Socio-Technical Scenarios** apparent from the TIA process;
- **Stakeholders**, stakeholder segments, their values and interests, and stakeholder proxies;
- **Benefits** that are foreseeable, with the focus on potential positive impacts, who are the likely beneficiaries, anticipated impediments to the realization of benefits, and possible means of overcoming the impediments;
- **Direct Impacts** that are foreseeable, who will suffer from the negative effects, and possible means of preventing and mitigating them;
- **Second-Round, Indirect Implications** that are foreseeable, who will suffer from the negative effects, and possible means of preventing and mitigating them;
- **Contingent Risks** that are foreseeable, who will bear those risks, and possible means of managing them; and
- **Technology and Application Design Features** for outcome equity, harm avoidance, harm mitigation, and risk management.

A further consideration is the pattern to be adopted in the conduct of the project.

B. Modus Operandi for the TIA

A TIA may be performed in a number of different modes:

- **An Authoritative approach**, with external engagement by outreach or consultation.
  By this is meant a study performed by a team that claims competencies in TA methods. Input from relevant parties may be welcomed, or at least considered, during the earlier stages (e.g., by means of a call for submissions on the technology's features, opportunities and threats) and/or after a draft position has been reached (seeking feedback on the draft);
- **A Coordinative / Collaborative approach**, with participation, as distinct from mere 'engagement'.
  In this case, the team is open-ended, or open at all stages to input from any interested party, particularly during the formative phases and again once a draft is in place. For a recent rendition of the history and features of participatory technology assessment (PTA), see [43];
- **A Competitive / Dialectic process**, of the nature of debate or dialogue. This follows an argument / counter-argument or thesis / antithesis / synthesis approach. It seeks the emergence of consensus or compromise, or if that cannot be achieved, then the publication of evidence and reasoned argument supporting two or more alternative interpretations.

The appropriate choice among these alternatives is likely to be driven primarily by the institutional and socio-political context. For example, a government agency team is likely to define the objectives and constraints of a TA, and devise its project process, very differently from a public interest advocacy association or an open collaboratory planning a TIA.

Some variations may be appropriate in the sequence in which the Elements in Table I are addressed. For example, where an Authoritative approach is adopted, an initial analysis of Stakeholders may be performed in the third step, with active involvement of advocates only being invited at a later stage.

A further aspect of project process that needs to be considered is the research techniques that are appropriate to apply during various phases of the overall TIA project.

C. Research Techniques

The large majority of established research techniques assume that relevant phenomena exist, are capable of being observed, and exhibit reasonable stability. In the context of emergent technologies, none of these assumptions holds. Hence, in many TIAs, observational methods are infeasible or heavily constrained. Further, little reliable information is available, and hence survey and focus group methods are limited in their applicability.

The worlds into which new technologies are introduced commonly feature emergent phenomena, unstable phenomena, and a high degree of interdependency among elements. These characteristics mean that sub-setting and simplification of the problem-space is difficult or infeasible, because of the large numbers of stakeholders with diverse perspectives, and value-conflicts. Many 'futures studies' techniques have been formulated, but they require careful molding to context and purpose, and their rigor is subject to challenge. Some techniques such as forecasting based on historical trends are seldom applicable because they cannot cope with the discontinuities that are common in technological invention and innovation. This section identifies key examples of techniques applicable to TIA projects.

Conceptual Research:

- **Conventional Delphi Studies:** These involve a request to a group of people with assumed expertise in the relevant domain to respond to a series of abstract propositions about the future. In one or more further rounds, the group is asked for responses to their peers' previous thoughts. The approach may deliver some insight into opinions, but its orientation is much less to the development of insight, and much more to the achievment of some kind of consensus, whether or not a diversity of opinions exists [69].
- **Visionary Depiction:** This comprises imagined futures, commonly 'utopian' (strongly emphasizing 'good' aspects), sometimes 'dystopian' (strongly emphasizing 'bad' aspects), and occasionally balanced, ambivalent or intentionally ambiguous. A common feature is the phrasing of speculations as though they were realistic or factual accounts [17], [36].
- **Critical Theory Research:** This is not usually portrayed as a futurist technique. It does, however, directly address the value-conflict challenge, by recognizing the effects of power and the tendency of some stakeholders' interests to dominate those of other stakeholders [16], [50].

Quasi-Empirical Research: Even if empiricism *per se* is precluded due to the absence of phenomena to observe, imagination can be applied in disciplined ways. The following techniques are quasi-empirical in nature, in the sense that they are apparently, but not really, oriented toward the observation of phenomena:

- **Grounded Delphi Studies:** Where participants begin with a sufficient and shared conceptual and/or technical base, the technique can be applied in a creative manner, seeking insights rather than consensus [63]. Examples could include perceptions of more likely innovation paths of small nuclear reactors, fusion power, quantum computing or space elevators.
- **Vignettes or Mini-Case-Studies:** These need to be grounded-but-imaginative. An example of an application to the Internet of Things is in [46, pp. 149-165].
- **Game-Based or Role-Playing Studies:** These need to begin with a sufficiently grounded setting, but then invite competition-spurred creativity [5]. They fit well with a TIA conducted using the Competitive / Dialectic approach.
- **Simulation Modelling:** Techniques such as Discrete Event Simulation (DES) and System Dynamics (SD) are feasible where a sufficiently simple yet realistic model of real-world phenomena can be expressed, and transactions conducted to reflect real-world actions [13]. For example, [25] applied the approach to social control aspects of public health in the context of the COVID-19 pandemic.
- **Scenario Analysis:** A scenario is a detailed description of what the future might be like, or a trajectory of possible, logically connected future events. The description is expressed as a story-line that represents 'an imagined but realistic world', applying socio-technical understanding. Scenario Analysis involves the development not of one Scenario, but of a requisitely-rich set of them [12], [54], [61]. The value derives from a

combination of the depth of insights achieved within each scenario, together with the diversity among the different scenarios' paths of development [23].

The last sub-section addresses the question of whether any particular TIA should restrict itself to providing a basis on which policy analysis can be undertaken, or should also make direct contributions to policy analysis.

D. Policy Analysis

The position adopted in this article is that policy analysis may be defined as being either within or beyond the scope of a TIA, depending on the circumstances. The decision may be externally imposed, through institutional structures, or it may be decided by project leaders.

Public policy may favor consequences such as faster travel, improved public health, stimulation of the economy, and the reduction of impediments to innovation.

Public policy activities also need to take into account the considerable body of **regulatory theory** [14], [30]. The applicability of existing regulatory regimes to new technologies is at best questionable, because they were designed for a previous technological landscape. They require continual 'reconnection' as technology changes [15]. A theoretical lens to assist in evaluating the fit between an existing regulatory regime and a new technology is provided by [7]. Other regulatory aspects of significance are:

- The existence of natural safeguards (which are often overlooked);
- The scope for many technologies to have infrastructural safeguards designed in, along the lines of the steam or 'fly-ball' governor (an opportunity that is too seldom exploited);
- The inadequacy of self-regulatory mechanisms (which are primarily window-dressing to avoid legislative measures, rather than safeguards and mitigation measures); and
- The easier achievability of effective and efficient safeguards through co-regulatory approaches rather than formal regulatory regimes.

Reference [24] discusses regulatory framework considerations for AI.

As discussed earlier, technologies evidence diverse features relevant to the assessment of their consequences. The meta-principle of 'technology neutrality' appears attractive. On the other hand, energy-production processes from each of coal, gas, sunshine, wind, tides, methane, hydrogen, fission and fusion need to be subjected to protective measures that are specifically relevant to those particular materials and processes. Policy expressed as principles that are abstract enough to apply to all of those forms is likely to be so vague as to deliver very little protection. An approach that avoids the blithe assumption that 'technological neutrality' is achievable involves the design of policy interventions at two levels:

- **Generic Policy based on Principles.** These need to avoid creating difficulties for particular forms of the technology and/or for particular application domains. For topical examples, see [24] re AI generally, and [26] re Generative AI in particular;
- **Policy Articulation into Operational Safeguards.** Applying to defined contexts within which the technology is used. These are preferably developed through co-regulatory arrangements in which all stakeholders are engaged, in order to take advantage of the depth of knowledge of people active in the particular field.

The following general guidance is also suggested, arising from discussions above:

- Policy proposals need to reflect the interests of a very wide range of **stakeholders and** of distinctly different sub-sets or **segments** within each group;
- Policy proposals need to have application to a wide variety of **domains of use**;
- Policy proposals need to cater not only for anticipated **trajectories** of innovation, application and adoption, but also for what appeared at the time to be low-probability scenarios. They also need to encourage adaptation for unforeseen eventualities;
- Policy proposals need to take account of **cultural diversity**, and in multiple ways. Value-sets differ between nations based on the extent to where they lie on particular cultural dimensions. Value-sets also differ within nations. In some cases, the distinction may be regionally-based, and in others associated with religion, ethnicity and/or language;
- Policy proposals need to **enable, facilitate and support, but also regulate;**
- Policy proposals need to **nurture innovation** during the early life of a new technology, but also to **ensure progressive strengthening of protections** in step with the technology's deployment; and
- Policy proposals need to address **outcomes equity**, across each of benefits distribution, harm avoidance, harm mitigation and risk-bearing.

This section has presented a Framework within which appropriate program plans for a wide variety of TIAs can be devised. Supplementary Paper 2 shows how the Framework supports the development of a project plan, by providing a small-scale, indicative application to delivery drones trialed in a suburban area.

VII. Conclusion

The primary contribution of this article is in the presentation of a TIA Process Design Framework, including framing, factors, and features, that offers intellectual support for the drafting of a preliminary TIA project plan. The approaches adopted by government agencies to Technology Assessment adopt too narrow a frame of reference to be of direct relevance to the contemporary need of teams conducting TIAs. The working definition of a TIA, as distinct from a TA, encompasses consequences of all kinds, not just positive impacts, avoids limiting the scope of technologies, applications and contexts, and applies no matter what organizational vehicle is used to perform the assessment. This article follows through the design science method steps of problem identification and definition of objectives, followed by design and development. A demonstration of the Framework's use is provided in Supplementary Paper 2. Evaluation of the TIA Framework is now necessary, by applying it to a variety of technologies at different levels of abstraction and granularity, in different application domains, and in diverse social, political and cultural contexts. Evaluation of the Framework will be aided if some uses extend to policy analysis, and others expressly limit their scope to laying the groundwork for researchers, government representatives and professionals to consider policy alternatives.

Presenting a framework rather than a tool may disappoint practitioners who are seeking a recipe or checklist, because it expressly demands considerable intellectual effort, and consideration of many sub-choices, before a preliminary project plan will emerge. On the other hand, this greatly reduces the likelihood of a project being commenced prematurely, before major challenges have been identified and confronted. A further use for the Framework is by individuals and teams seeking funding for a TIA, who may find it a valuable tool in workshopping the funding bid, along the way debating alternative orientation, scope and project mechanics.

The article has implications for researchers, because it poses challenges to existing bodies of theory relevant to TAs and TIAs. The level of intellectualization of academic contributions in the area is admirable, but much of it does not bring the intellectual insights down to a level at which they offer value to practice.

Of particular importance in this regard is the lack of distinction made among the various alternative scope definitions that TA processes can adopt. The guidance available for the conduct of TAs has contracted to the very narrow worldview of the government bureaucrat, with economic motivations dominant. The consequences that are prioritized are the benefits, and the stakeholder-sets considered are narrow. The social and environmental dimensions and the impacts, implications and risks are all under-emphasized, especially those affecting less-powerful stakeholders, including users and particularly usees.

If it is to service public needs in a period of extremely powerful technologies, the body of theory available from which to articulate guidance for the conduct of TIAs needs to address these deficiencies.

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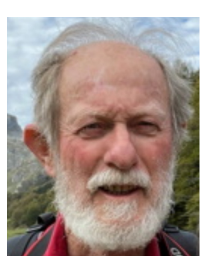

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