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Key principles for developing industrially relevant strategic technology management toolkits

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ABSTRACT

When considering the potential uptake and utilization of technology management tools by industry, it must be recognized that companies face the difficult challenges of selecting, adopting and integrating individual tools into a toolkit that must be implemented within their current organizational processes and systems. This situation is compounded by the lack of sound advice on integrating well-founded individual tools into a robust toolkit that has the necessary degree of flexibility such that they can be tailored for application to specific problems faced by individual organizations. As an initial stepping stone to offering a toolkit with empirically proven utility, this paper provides a conceptual foundation to the development of toolkits by outlining an underlying philosophical position based on observations from multiple research and commercial collaborations with industry. This stance is underpinned by a set of operationalized principles that can offer guidance to organizations when deciding upon the appropriate form, functions and features that should be embodied by any potential tool/toolkit. For example, a key objective of any tool is to aid decision-making and a core set of powerful, flexible, scaleable and modular tools should be sufficient to allow users to generate, explore, shape and implement possible solutions across a wide array of strategic issues. From our philosophical stance, the preferred mode of engagement is facilitated workshops with a participatory process that enables multiple perspectives and structures the conversation through visual representations in order to manage the cognitive load in the collaborative environment. The generic form of the tools should be configurable for the given context and utilized in a lightweight manner based on the premise of 'start small and iterate fast'.

1. Introduction

Within the business strategy research community, there has been a call to refocus the emphasis toward the human activity [1]; that is, to concentrate more upon the "micro aspects of how managers think, act and interpret strategic decisions" [2]. This is known as the strategy-as-practice perspective, where the "thrust is to dig into what managers actually do when they strategize" [3]. Strategy is therefore now seen as something individuals do as opposed to something that an organization has [1]. "Thus the practice perspective is concerned with managerial activity, i.e. how managers do strategy" [2]. For such a perspective, Whittington [4] proposed three elements for a theory of practice, namely: praxis, practices and practitioners. Praxis refers to the situated and socially accomplished flows of activities that are strategically "consequential for the direction and survival of the group, organization or industry" [5]. Whereas practice refers to the tools and models for enabling action [6] along with their associated organizational specific embedded routines [4]. This strategy-as-practice view has been adopted as an interpretative lens for the study of strategic technology management (STM) with an initial focus of inquiry on the tools/toolkits adopted and used by practitioners for supporting

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their decision-making. Such STM tools take many forms; for example: charts, checklists, diagrams, graphs, grids, maps, matrices and tables. Additionally, different combinations of these forms are also readily found [7]. The study of tool development and application has been selected for investigation because "effective management of technology requires practical management tools to support decision-making and action" [8]. Taking the practice perspective, McGahan's [9] paper on 'academic research that matters to managers' states that "managers don't care about disciplinary boundaries. They want to know how to solve specific problems quickly". Thus it can be said that in the practical setting, managers are problem-driven and application-oriented [10]. This requires both an integrative approach to toolkit development and the acceptance of the transdisciplinary nature of tool utilization in industrial engagements. Additionally in the real-world context for tool adoption and application, managers "are usually more concerned about finding good, politically feasible solutions, instead of optimal ones" [11]. Therefore the aim of any tool should be to satisfy the user in finding a set of 'good' options that have the potential to provide clear improvements in their organization and which are deemed implementable at the same time [11–13]. In using tools to support decision-making, the belief is that "although we are not perfect decision makers, we can do better through more structure and guidance" [14]. Such guidance should give a consistent recommendation on tools to adopt and apply across the range of problems typically encountered in technology management. However as noted by Whitney [15] on assembling a technology development toolkit, they usually consist of a 'favorite collection of tools' that is built over time through discovery and experience. The problem is clearly articulated by Phaal et al. [16] who state that "the effectiveness of these tools is limited by a lack of fundamental understanding of the structure and application of management tools, together with generally poor levels of awareness of what tools are available". Additionally, one of the key concerns in technology management is that the tools are often presented, treated and used in isolation along with insufficient integration with other tools [17]. This situation is exasperated by the proliferation of tools and associated approaches developed by academics and consultants. For instance, a study by Phaal et al. [7] identified over 850 tools based on the simple 2×2 matrix. This can lead to potential confusion in the choice of which tools to use and how to deploy them most appropriately [8]. It has also been noted that the proliferation of tools carries with it "little consistency in terminology or theoretical foundation, and a lack of understanding of how such tools can be linked together to tackle management challenges in an integrated way" [8]. To address the degree of rigor that must be applied to the challenge of providing tools that are 'practically relevant and academically sound', a number of issues posed by Phaal et al. [16] need to be addressed:

- How to find the appropriate tools?
- How to assess the quality and utility of the available tools?
- How to apply the tools in a practical setting or process?
- How to integrate tools with other tools, and with business processes and systems?

This list was later extended by Phaal et al. [8] to include two other important issues:

- What is the minimum set of tools that can be used to build the toolkit?
- What are the rules for generalizing, integrating and configuring these tools?

Phaal et al. [8] put forward the vision of a "universal toolkit that can be configured to support a wide range of technology management decisions and processes" whereby the toolkit would "comprise the minimum set of generic tools required to solve the class of problem for which they are designed, together with guidance on how to integrate, configure and deploy them". To make a start on the journey of attempting to realize such a vision, this paper proposes seven guiding principles that provide an initial conceptual foundation for STM toolkits and which should be operationalized during their development. The principles emerged from an inductive reflection of multiple (>200) research and commercial engagements with industry. Their description is substantiated by the pertinent literature. Essentially, these principles embody our underlying philosophy for developing and deploying industrially relevant strategic technology management toolkits.

2. Strategic technology management

In order to outline a number of principles for operationalizing a set of tools into a STM toolkit, it is first necessary to consider the essence of technology management and the meaning assigned to the terms 'strategic' and 'tool'. The key reference point in arriving at a conceptualization of technology management that mutually spanned both the academic and industrial spheres was the ISAEP process framework put forward by Gregory [18] as depicted in Fig. 1. According to Gregory [18], technology management "addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies needed to maintain a stream of products and services to the market". The specific elements embodied in this definition are further articulated in Table 1. Additionally, Phaal et al. [19] state that technology management is concerned with "establishing and maintaining the linkages between technological resources and company objectives". Thus, technology management is a "multifunctional and multidisciplinary field" as it "deals with all aspects of integrating technological issues into business decision-making and is directly relevant to a number of core business processes including strategy, innovation, new product development and operations management" [19].

Although Gregory's [18] original process framework is an excellent foundation for defining technology management, there is the possibility of updating it in a number of ways to allow for a further degree of explanatory power. Fig. 2 shows the next iteration in design where the following modifications are proposed:

1. Technology (technological resources) has been put in the center of the framework.
2. The protection process is shown as surrounding the technology base.

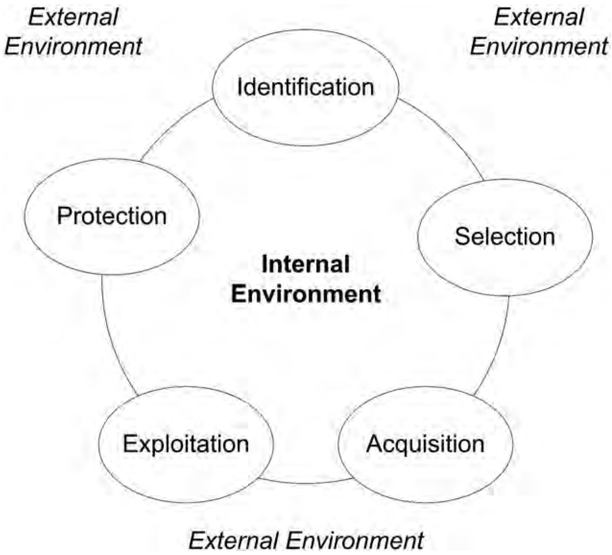

Fig. 1. ISAEP process framework.
Adapted from Gregory [18].

3. The other four processes (Identification, Selection, Acquisition and Exploitation) are drawn as gears to signify that they need to be brought together (meshed) in order to be configured for use by an organization.
4. In order to utilize the framework within a given real-world context, there needs to be a co-ordination element that acts as the 'oil' between all of the processes.
5. Introduced around the outside of the framework are the three core business processes of strategy, innovation and operations (SIO). These provide the necessary connections between the technology management processes and the wider business activities. For a detailed explanation of the relationship between the ISAEP and SIO processes refer to Phaal et al. [19].

Within the technology management literature, a most concise explanation of a tool and related terms is given by Phaal et al. [19]; who provide the following deductive logic:

- A 'process' is an approach for achieving a managerial objective, through the transformation of inputs into outputs.
- A 'procedure' is a series of steps for operationalizing a process.
- A 'technique' is a structured way of completing part of a procedure.
- A 'tool' facilitates the practical application of a technique.

Having given a brief outline of what technology management embodies and the meaning associated with the term 'tool', it remains to distinguish the significance of the term 'strategic'. According to Normann [20], strategic thinking is associated with addressing the following set of questions:

- What are we doing?
- What could we be doing?
- What should we be doing?

Table 1
ISAEP process framework.

Process	Gregory [18]	Phaal et al. [19]
Identification	Involves developing an awareness of all the technologies, which are, or may in the future be, important to the business.	Identification of technologies that are not currently part of the firm's technology base, but may be important in the future.
Selection	Involves the choice of technologies that should be supported and promoted within the organization.	Selection of those technologies that the firm needs for its future products.
Acquisition	Involves decisions about the appropriate means of acquiring selected technologies and embedding them effectively within the organization.	Acquisition of the technologies that have been selected.
Exploitation	Involves the systematic conversion of technologies into marketable products, or alternatively the realization of their value through sale or joint venture.	Exploitation of the technologies that have been acquired.
Protection	Involves the preservation of the knowledge and expertise that are embedded in products and manufacturing systems.	Protection of the technological assets of the firm.

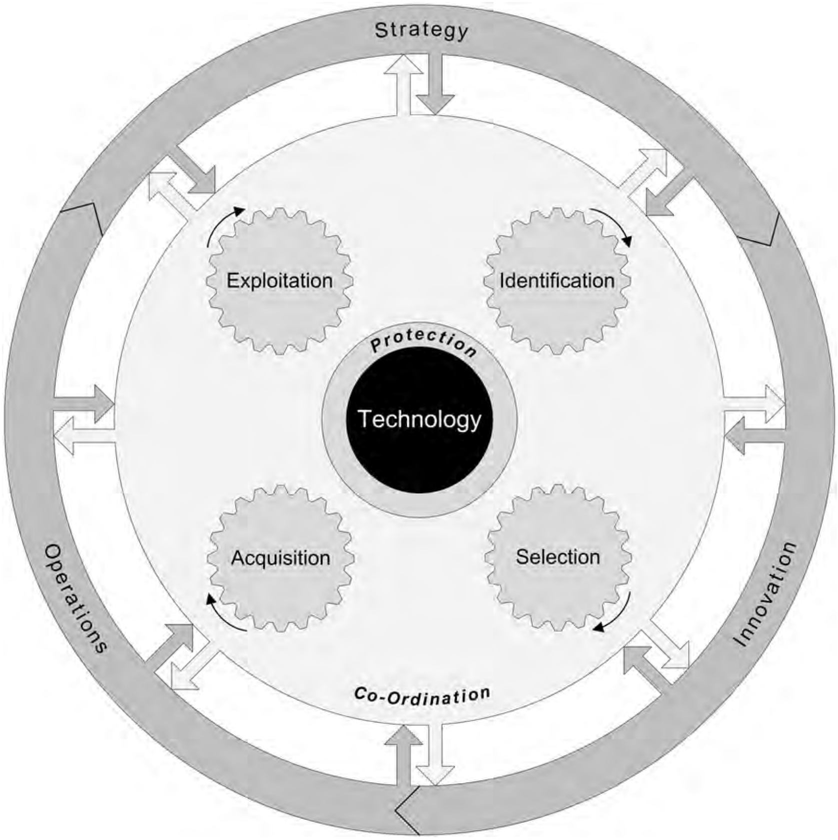

Fig. 2. STM framework wheel.

"The first question focuses on the self, the second on the environment and the options it presents, and the third on strategic decision-making" [21]. In terms of relating this perspective into the context of management and business strategy, Mintzberg et al. [22] state that "strategic simply means important in terms of the actions taken, the resources committed, or the precedents set". Thus, as popularized by Mintzberg et al. [22] "strategic decisions are seen as large, expensive and precedent setting; producing ambiguity about how to find a solution and uncertainty in the solution's outcomes" [3]. The work of Nutt and Wilson [3] provides the most comprehensive set of characteristics for strategic decisions, namely:

- They are elusive problems that are difficult to define precisely.
- They require an understanding of the problem to find a viable solution.
- They rarely have one best solution, but often a series of possible solutions.
- Questions about trade-offs and priorities appear in the solutions.
- Solution benefits are difficult to assess as to their effectiveness, in part because that lack a clear final end point against which effectiveness can be judged.
- Other problems in the organization are connected to solutions for a focal problem.
- High levels of ambiguity and uncertainty are associated with solutions.
- Realizing hoped for benefits has considerable risk.
- Strategic decisions have competing interests that prompt key players to use political pressure to ensure that a choice aligns with their preference.

3. Guiding principles

The vision of a 'universal toolkit' for technology management is quite a challenge given that one of the significant contributing factors to the proliferation of 'new' tools is that the academic community of tool developers often considers the concept of 'an original contribution to knowledge' as signifying the need to constantly create newer forms/versions of specific tools. What is also apparent from the literature is the imbalanced focus on the generation of 'new' tool variants (i.e. the number of tools being published) versus evidence as to the uptake of such tools by industry (i.e. longitudinal case studies) and their subsequent assimilation into a company's standard practices. There have been steps towards addressing such concerns through the approach of combining well-known tools in an integrative manner. For example, there is the top-down integrative toolkit of Phaal et al. [8] which combines the three tools of roadmaps, portfolio matrices and linked analysis grids (e.g. quality function deployment). There is also the set of tools brought together by Kerr et al. [23] in a bottom-up manner for specific application in the area of technology insertion. However in order to develop a universal toolkit that is generalizable and transferable, a step back must first be taken to reflect upon the characteristics that would appear to have an inherent resonance with the actual practice of technology management and those involved with its associated processes and decision-making tasks.

There have been some initial analyses on the characteristics of technology management tools. Two of the earliest studies were conducted by Brown [24] and Farrukh et al. [25]. Brown [24] observed a number of 'good practice' principles, which included such factors as the tools should be:

- Founded on an objective model.
- Flexible so as to 'best fit' to the current situation and needs of any organization.
- Accommodating to the collection of views through all levels within the firm.
- Attentive to differences in assessments/perceptions between different groups.
- Simple in style of presentation.
- Designed in a clear graphical and visual manner.
- Linked with other methodologies and implementation aids.

Building upon those factors Farrukh et al. [25] highlighted a further number of dimensions, for example:

- The importance of supporting communication and buy-in.
- The importance of the format of application (e.g. workshops) and the packaging of the methodology (e.g. workbooks).
- The need to achieve 'apparent simplicity' (e.g. by using multiple layers to handle complexity).
- The need to be accessible (i.e. user-friendly structure and process).
- The provision of an appropriate graphical style/interface.
- The provision of multiple entry points to allow the 'drilling' into different levels of a firm.
- The ability to be expandable and customizable.
- The ability to link to other tools.

Farrukh et al.'s [25] list was added to by Phaal et al. [16] to include:

- Simplicity and transparency (in structure and application).
- Easy to learn and apply.
- Modular structures and common information requirements.
- Flexibility and extensibility, and a good fit with standard business processes and systems.
- Based on sound and widely adopted business theories, models and frameworks.

Phaal et al. [7] later updated their set of characteristics with:

- Robust (i.e. theoretically sound and reliable).
- Economic and practical to implement (i.e. not too complex or resource intensive).
- Integrated (i.e. work together and link to other frameworks, processes and tools deployed in the business).
- Flexible (i.e. adaptable to suit the particular context in terms of business purpose, market environment, available resources and information, and corporate culture).

And:

- Developed in a robust manner, using appropriate research methodologies, based on well-founded frameworks underpinned by appropriate management theory [8].
- Tested in a wide range of practical management contexts, addressing real-world problems [8].

Although the works of Brown [24], Farrukh et al. [25] and Phaal et al. [7,8,16] act as a valuable resource, the stream of output is actually a growing list of factors. Thus, there needed to be a rationalization of the material into a consolidated form. So it was necessary to consider and take into account these previously cited tool characteristics during the distillation of the principles reported in this paper. The set of principles emerged from an inductive reflection of more than 200 applications of tools/toolkits at both the business (corporate and business unit) and industry levels (government, trade associations and research networks). These applications were through consultative industrial engagements with the aerospace, automotive, chemical, construction, defense, electronics, fast moving consumer goods, food, instrumentation, logistics, manufacturing, materials, not-for-profit, oil and gas, packaging, pharmaceutical, rail, services, software and telecommunication sectors. The result was the identification of seven principles that provide a conceptual underpinning for the development of practically relevant and academically sound STM tools/toolkits. Each of the principles will be discussed in turn and will be substantiated/reinforced by the key supporting literature. It must be acknowledged that a significant number of the citations are from the authors' body of work that has been built-up on the subject of technology management tools and in particular on roadmapping. The seven principles are:

1. Human-centric
2. Workshop-based
3. Neutrally facilitated

4. Lightly processed
5. Modular
6. Scalable
7. Visual

3.1. Human-centric

The first principle is that the tools should be '*human-centric*' — that is, a tool should provide the opportunity for individuals to participate and engage with one another leading to a co-created solution which embodies their meaningful collaboration and generates a useful product from the result of their social interaction. At its base, strategic problem solving in organizations is, after all, a social process [26]. For instance, the strategy-as-practice perspective explicitly acknowledges that strategy should be conceptualized as a situated socially accomplished activity [5]. Consider Fig. 3 for example, it captures a typical human-centric scene that is readily recognizable by managers. According to Nutt and Wilson [3], the social practice of decision-making should be acknowledged and emphasized. The rationale being that problems are socially constructed entities where "their nature and salience will depend on how managers subjectively construct them" [11]. Therefore, the use of tools should also reflect the social nature inherent in exploring, addressing and solving strategic technology management issues. For example, tools should be able to cope with the fact that "different managers will perceive a given problem situation in quite diverse ways, due to their distinct interests and foci and, therefore, will describe the situation according to those perceptions" [11].

Tool developers must appreciate the situational factors of real-world applications by taking into account the cultural, sociological and psychological aspects of the human-centric setting. In considering the human-centric nature of managerial practice, especially in regard to problem solving and implementation, Eden [26] draws attention to the importance of Simon's [27] considerations of both procedural rationality and substantive rationality (i.e. means/ends). These two aspects have a direct influence of how toolkits are perceived and used in real-world settings. That is, for tool use to be effective, these two forms of rationality should be considered in order to address issues such as process visibility, accountability and buy-in. In effect, the process involved in applying the tool should address procedural rationality — "we followed an appropriate process" [26]. Whereas, the content resulting from the use of a tool should address substantive rationality — "it makes sense, a case can be made, reasons can be stated" [26]. Additionally, in deploying tools in a real-world setting, the cultural aspects must be carefully considered and handled to ensure the appropriateness of their application. Account may need to be taken of differing human dynamics and associated practices in corporate settings of Western organizations to those of Eastern counterparts.

The case for the human-centric principle can also be made by considering the advantages of this orientation in terms of group decision-making; Brodbeck et al. [28] highlight the following beneficial properties:

- The identification and integration of individual viewpoints.
- The combining and integrating of different knowledge, ideas and perspectives.

Using tools with groups should lead to high-quality decisions and innovations because there is access to more and a broader range of information since the unique knowledge is distributed among the group members [28]. Checkland's [29] 'systems thinking' reinforces the point by arguing that by allowing mutual exploration it "enables the accommodation of multiple and differing positions among participants". Additionally, activities such as foresight within technology management are a transdisciplinary exercise [10] and as such require a human-centric approach to be taken. Tools should allow managers to "jointly define the situation, make sense of it, negotiate a shared problem definition, and develop and evaluate a portfolio of options" [11]. In terms of permitting participation in

Fig. 3. Human-centric.

decision-making, the representative and integrative functions of utilizing a tool with a number of participants also have benefits for the acceptance of the output [28] and in promoting team building [30]. There may also be an "emotional commitment from the participants in relation to a solution" [26].

As an example, consider some of the human-centric benefits that can be realized from applying roadmapping. According to Phaal and Muller [31], "it is often claimed that the process of developing a roadmap is more valuable than the roadmap itself, because of the associated communication and consensus generated between functions and organizations". For instance, in the process of applying the tool, participants are encouraged to get up and look over the roadmapping wall chart between iterations of ideation. From a psychological perspective, the visual form of the sticky notes on the wall chart provides a strong sensory input to facilitate cognition. This visual depiction of the group's collective thoughts provides social stimulation and priming of associative memory for improved idea generation [32]. Also, from the sociological perspective, the linkages that are captured on the roadmap are important as they reflect the relationships between stakeholders and so the developed roadmap can be considered as being the visible statement of that social contract [33].

3.2. Workshop-based

Given that "engagement is all about participation" [34], the second principle is '*workshop-based*' — that is, the recommended mode of engagement for deploying/applying an STM toolkit should be through workshops. An example of which is depicted in Fig. 4. Workshops are essentially an engagement mechanism for group interaction by structuring activities around using the tools for solving strategic problems. In the context of a workshop, participants are interdependent, i.e. there is a mutual reliance on each other for the needed knowledge [35]. Mutual reliance is of course critical when considering issues that are strategic to an organization because they are inherently complex and typically require the combined efforts and knowledge from a range of people [36–39]. The key premise of group engagement is that the successful integration of the various pertinent viewpoints provides a higher quality basis for decision-making [40]. Therefore, since the integration of knowledge from a set of individuals into collective knowledge is a fundamental activity of group work [41], a workshop provides a natural setting for such pulling together of knowledge. According to Phaal et al. [42], workshops represent the primary mechanism whereby the stakeholders and domain experts are brought together to capture, share and structure knowledge relating to the strategic issues facing an organization. Thus, the power of the multifunctional workgroup is in the social interaction and exchange that takes place during the arranged activities. In terms of the applicable scope of the '*workshop-based*' principle, the default situation is physical meetings; however virtual arrangements and real-time online tools to support the physical workshop are being explored as mechanisms which allow participation from individuals who are not able to attend the meeting but can still have an input and degree of interaction.

Fig. 4. Workshop-based.

Another aspect for situating the use of STM tools within a workshop is the positive reinforcement that comes with attending a workshop (i.e. being given the opportunity to put forward your views) and actively participating (i.e. having your views recognized by your peers). Additionally, participation of key stakeholders increases the level of commitment for implementation post-workshop [11,43–47]. According to Franco and Montibeller [11], the rationale for this is that their “involvement will make stakeholders more confident in the analysis performed and more committed to the recommendations derived from it”. Such confidence and commitment will be strengthened if: (i) the participants believe that their views, preferences and objectives were taken into account; (ii) the activities adequately portrayed the problems they wanted to solve; (iii) the assumptions made were organizationally realistic; and, (iv) the solutions found in the analysis were sound and justifiable [11].

Consider again the case of roadmapping, Phaal et al. [33] state that “people should be the focus when using roadmapping at the front-end of innovation and strategy” and describe cross-functional workshops as being a core ingredient with Cambridge's baseline process being configured for a one-day workshop [42]. Thus, roadmapping as a process is centered on the workshop approach where the function of the workshop is to engage in a process of group inquiry and consensus building through which the participants' cognitive efforts are combined [48]. It is a socially facilitated mechanism for the purpose of group cognition with the ‘real’ power of the roadmapping workshop coming from the group interactions and combined effort as a collective [48]. In examining Phaal et al.'s [42,49,50] empirical approach and visually-orientated scheme under a psychological and sociological lens with the workshop as the unit of analysis, a psychosocial framework was developed by Kerr et al. [48] that puts forward the proposition that the adoption and practice of roadmapping/roadmaps provide a mechanism/vehicle to cogitate, articulate and communicate. Firstly, the ‘*cogitate*’ verb embodies the intellectual feats that are exhibited within the workshop. At the front-end, there is the creative thinking to generate and refine ideas. During the later phases of the roadmapping activity there is the need for the participants to generalize, infer, integrate and pattern ideas. Once a roadmap has been generated, there is also the need to reflect and deliberate with the wider audience within respective departments and organizations. Secondly the ‘*articulate*’ verb encapsulates the actions of workshop participants in expressing themselves, in terms of their mental models (providing the context) and their ideas (providing the content), through both speaking and writing components. The textual production elements are manifested through pen and paper to generate a roadmap whereas the auditory component provides a verbal overlay during the task. Finally, the ‘*communicate*’ verb represents roadmapping as a workshop activity for participants to actively converse and a roadmap as a vehicle to convey the results of the activity and connect with the array of stakeholders via a living document. Post-workshop, the produced roadmap is a communication device that helps not only to share information to other parties for strategic dialogue but more importantly to mobilize action.

3.3. Neutrally facilitated

The third principle is ‘*neutrally facilitated*’ — that is, the workshop within which the STM tools are to be applied should be facilitated from a position of neutrality. As shown in Fig. 5, the highlighted facilitator is important for structuring/running the process but should be removed from the discussions between participants. Before addressing the meaning of neutrality, first consider the proposal of bringing in a facilitator. By having a facilitated workshop, the participants are guided through the tasks in the process, interactions with each other and the STM tools being applied. As such, proponents of using facilitation see it as a means to assisting participants to become the ‘architects of their own future’ [51–53]. Franco [54] equates facilitation with allowing the participants to hold ‘designed’ conversations in order to exchange their understandings and views about the situation that is being analyzed. According to Rasmussen et al. [10], a skilled facilitator can “create a space for dialogue and exploration in a contested territory”. “The general purpose of group facilitation is to enable participants to work together much more effectively in resolving the issues of concern that brought them together” [11]. To achieve this, Kaner [53] states that the facilitator should:

- Encourage full participation.
- Promote mutual understanding.
- Foster inclusive solutions.
- Cultivate shared responsibility.

Additionally, Franco and Montibeller [11] highlight the benefits of facilitated interventions as:

- Allowing managers to share and increase their individual understandings of the problem situation of interest.
- Helping managers to articulate their preferences.
- Enabling managers to appreciate the potential impact of different options.
- Supporting the negotiation of courses of action that are politically feasible.

This now leads to the matter of addressing the meaning of neutrally facilitated. The work of Vennix [47] provides the clearest explanation. Vennix [47] makes the “distinction between content (the subject matter under discussion), procedure or method (the way a problem is tackled) and process (the way group members interact with each other) in a meeting”. Under this definition, “group facilitation concentrates primarily on procedure and process, not on content” [47]. Therefore, neutrality signifies that “the facilitator must be neutral with respect to the content of the discussion” [47]. “Without giving advice, evaluating progress or contributing to content”, Phillips and Phillips [55] have identified six different ways that the facilitator can intervene while maintaining their neutral position. They are: pacing the task, directing, handing back in changed form, reflecting, questioning and summarizing. An explanation for each of these is given in Table 2. Phaal et al. [42] actually go farther by inferring that really only the pacing intervention

Fig. 5. Neutrally facilitated.

is required since, ideally, "the process is self-sustaining and the role of the facilitator largely focuses on time keeping". The use of structured visual templates provides significant support in realizing such lightweight 'self-organizing' activities. This, of course, requires careful planning to ensure that the architecture of the tools is sound and that appropriate participants are involved since "success is largely determined by the active involvement of those participating" [42].

3.4. Lightly processed

The fourth principle is '*lightly processed*' — that is, the process for using the STM tools within the workshop should be applied in a lightweight manner based on the premise of 'start small and iterate fast' and also have a degree of flexibility by not being too prescriptive. It is important to note that "workshop agendas, activities and facilitation techniques need to be adapted to suit the group size" [33]. The process associated with running the workshop and applying the tools should be viewed as a means to structure the discussion and guide the elicitation of the strategic narrative from the participants. "Conversations are considered a fundamental aspect of strategy-making", with this in mind Franco [54] developed a typology of the different forms of conversation that can take place when applying tools in organizational interventions. The five forms of conversation are given in Table 3. For the purposes of applying a STM toolkit to support the conversation and aid decision-making, the most relevant forms are dialogue, negotiation and deliberation. This is because the objective is to work together towards a mutual understanding [56] so as to reach an agreement on how to carry out an action [54] based on an informed and thoughtful basis [57]. These forms of conversations can then

Table 2
Allowable facilitator interventions [55].

Intervention	Description
Pacing	Pacing the task is a process intervention that influences the timing of the group work. The facilitator may speed or slow the group work not only to ensure that the activities are given adequate time to accomplish the task, but also to achieve the objectives within the time limits.
Directing	Directing the group relates to introducing a new activity, or getting the group to evaluate its progress, so as to help them accomplish the task.
Handing back	Handing back in changed form signifies the idea of reporting back what has been observed, but from a different perspective. That enables participants to hear it, since much is familiar, but the addition of a new perspective provides a new meaning for them, and helps the task to go forward.
Reflecting	Reflecting back by making statements such as "You seem to be saying …" is to encourage further exploration of a topic when the discussion falters.
Questioning	Questioning, especially when some participants are using jargon or unfamiliar concepts, can help other group members to more fully appreciate the content of the discussions. When conflicting or confused answers are received from the group, exploration may reveal that members have taken for granted the meaning of words that, in fact, have been understood differently.
Summarizing	Summarizing a discussion, whether verbally or with a drawing, phrase or sentence, can help a group to test consensus. More importantly, it can mark an important milestone, 'erasing' the group's history and freeing them to move on to the next stage of their work.

Table 3
Types of conversational forms [54].

Conversation type	Initial situation	Conversation goal
Debate	Conflict of opinion	Win argument
Persuasion	Conflict of opinion	Persuade other party
Dialogue	Conflict of opinion	Shared understanding
Negotiation	Conflict of interest	Settlement
Deliberation	Need for action	Thoughtfully based action

be designed for engagements with industry by configuring a generic process (Fig. 6). The generic lightweight process can be structured around three fundamental dimensions, which can then be tailored for specific instances. The three dimensions are:

- Macro – Micro
- Divergent – Convergent
- Plenary – Small group

The macro–micro aspects of the process relates to how the overall process will be rolled-out. The macro level considers "the broad steps needed in the short-, medium- and long-term" by an organization [8]. This typically corresponds to periods of weeks and months [33]. It takes into consideration how the engagement will be aligned with core business process deadlines, e.g. a new product development stage gate [33]. Whereas the micro level is associated with the short-term and, particularly, the agendas for specific workshops [8]. Thus, it is the series of individual micro level workshops that are run which then feed into the macro level to realize the goals of the participating organization. One important aspect of the process, highlighted by Phaal et al. [50], which needs to be considered carefully by an organization is the trade-off between the level of resources committed (time and money) and the quality of the output (information content and decisions). Phaal et al. [50] have found that a one-day workshop is normally sufficient as an initial reference point in order to achieve an acceptable level of commitment to ensure good participation. Additionally, Phaal et al. [50] have identified a number of factors that need to be considered when translating the generic process into specific cases:

- Ownership — A clear business purpose and business problem owner.
- Scope — The boundaries of the domain of interest.
- Focus — The focal issue that is driving the need.
- Aims — Goals and objectives that the organization hopes to achieve.
- Resources — The level of resource that the organization is willing to contribute in terms of people, effort and money.
- Participants — A multi-functional team representing both the commercial and technical perspectives.

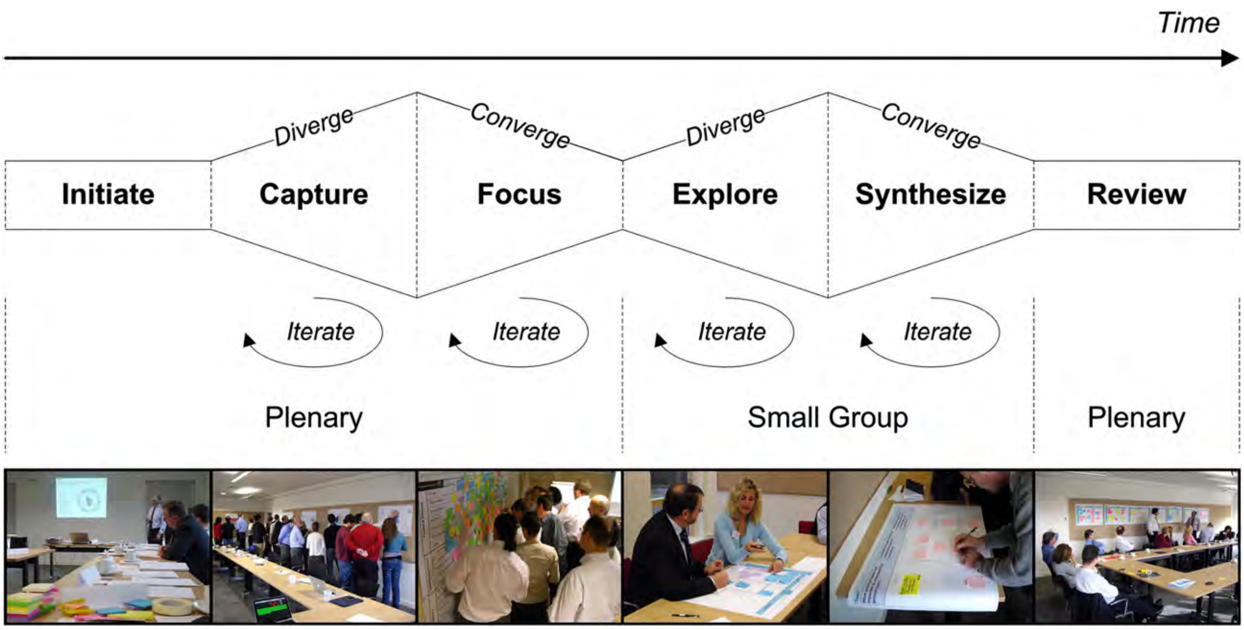

Fig. 6. Lightly processed.

The generic lightweight process, presented in Fig. 6, is based on a divergent–convergent construct. It consists of six stages with two divergent–convergent phases that can be iterated around as necessary. The use of sequential diverging and converging stages originated from the early work on creativity. Osborn's [58] book on brainstorming, for example, recommended having a divergent stage for generating ideas which is then followed by a convergent stage for focusing options. Such a divergent–convergent scheme can be found in numerous works. For instance, it implicitly appears in Franco and Montibeller's [11] facilitated modeling where group work is organized into the phases of: structuring the situation and agreeing a focus; developing a model of organizational objectives or systems; creating, refining and evaluating option actions; and developing action plans. Also, there is the example of Phaal and Muller [31] where it appears explicitly in their iterative phased approach of:

- Ideation — Design and scoping.
- Divergence — Scenarios, exploration and opportunities.
- Convergence — Weighting, analysis and selection.
- Synthesis — Visualization, packaging and communication.

Two procedural aspects do warrant special attention as they are often overlooked in designing implementation processes for STM tools, they are: clustering (Fig. 7) and prioritizing (Fig. 8). In terms of clustering, Tassoul and Buijs [59] argue for a distinction to be made in divergent–convergent processes to recognize clustering as a separate stage. Their proposition is that clustering is neither a form of divergence (you do not add new ideas) nor a form of convergence (you do not discard any ideas). Clustering should be seen as a “separate in-between step just for ordering the ideas in understandable and recognizable categories” [60]. Additionally, “although clustering can be a process of synthesis or integration, it is also a process of reduction” whereby the richness of a large set of initially isolated ideas is reduced down to a limited number of clusters [59]. Tassoul and Buijs [59] also distinguish clustering from categorizing because clusters are arrived at by connecting ideas into groupings in a generative ‘bottom-up’ manner whereas categorizing is about fitting ideas into set categories. The work of Tassoul and Buijs [59] identifies four types of clustering. These are given in Table 4 and can be readily adopted in processes for operationalizing STM tools. There is also the aspect of prioritizing (Fig. 8). This step needs to be democratic in the sense that all of the participants have the opportunity to be involved in the voting/ selection and that the means to arriving at the chosen set is transparent to all. Finally in respect of process considerations, there is the dimension of plenary versus small group. As can be seen in Fig. 6, the process is initiated with a plenary and this setting is maintained for the capture and focus steps. The large plenary group is then split into small work groups in order to study the topics/problems in greater depth, perhaps by using different tools, and to then synthesize solutions and/or generate recommendations. These small groups then rejoin in the plenary review session to report back their individual findings and as a collective agree a series of actions to: (i) carry the work forward and (ii) to maintain the necessary momentum; which will hopefully lead to successful implementation and subsequent resolution.

3.5. Modular

The fifth principle is ‘*modular*’ — that is, STM toolkits should be built in a modular fashion with their constituent tools being readily integrated with one another (Fig. 9) and that the combined final output or product of using the tools should also be able to have a composite form (Fig. 10). Fig. 9 illustrates the modular nature of the vision of a universal STM toolkit. The basis for the modular toolkit is the underlying concepts proposed by Phaal et al. [8] in terms of generalization, configuration and combination as outlined in Table 5. The STM toolkit should be comprised of a small set of core tools that have a totally generalized form that can then be configured to a specific format when referenced to a particular application/purpose/process. Phaal et al. [8] state that “it is unreasonable to expect that a particular tool will be suitable without customization (it is important to adapt the tool to fit the

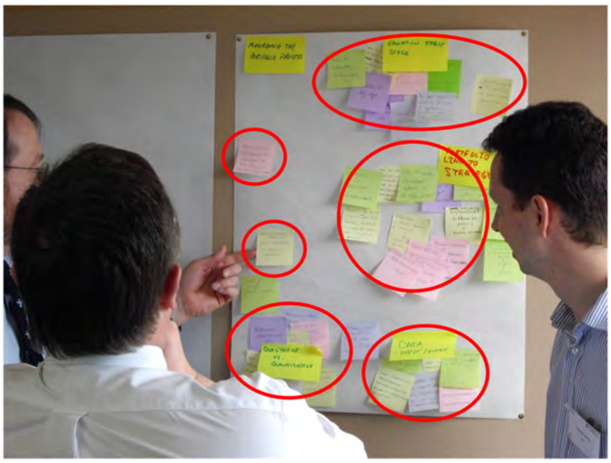

Fig. 7. Clustering.

Fig. 8. Prioritizing.

situation, rather than compromise requirements to fit the available tool)". This essentially provides the necessary functionality for achieving flexible alignment. The tools can then be combined and applied in a consolidated fashion for industrial engagements via workshops. Such combination or integration, i.e. how well different tools work together, is according to Phaal et al. [16] key for successful development and application of management tools.

The modular principle is borrowed from the area of product design and systems engineering; where modularity is the means by which a final product is assembled from separate independent modules with each system performing distinctive functions [61–63]. Modularity, at its most abstract level, simply refers to the "degree to which a system's components can be separated and recombined" [64]. It is the recombination that provides the utility of a modular design [62]. According to the work of Schilling [64], "a general theory of modularity can be defined as the degree to which the components of a system can be separated and recombined to create a variety of configurations without losing functionality" [65]. Modularity "increases the number of possible configurations achievable from a given set of inputs" thus "greatly increasing the flexibility of a system" [64]. This is essentially what the illustration of the modular STM toolkit in Fig. 9 depicts as it moves from the generalized form to the specific form. Related to this concept is the loose coupling of component designs within a modular architecture which allows the 'mixing and matching' of components so providing a potentially large number of product variations with distinctive functionalities, features and/or performance levels [63]. This aspect of modularity for a STM toolkit is represented in Fig. 9 as combining the specific forms of the individual tools and then applying them in their consolidated form as an offering to industrial clients. The combining of the

Table 4
Types of clusters [59].

Cluster Type	Description
Object	Object clustering is mainly aimed at categorizing ideas into an overviewable set of groups of ideas. No special connections are being made, other than looking for similarities.
Morphological	Morphological clustering is used to split up a problem into sub-problems after which the ideas generated are considered as sub-solutions which can then be combined into concepts.
Functional	Functional clustering is interesting when different approaches can be chosen to answer some question. It permits a more strategic choice to be made.
Gestalt	Gestalt clustering is a more synthesis like approach, often with a more metaphoric and artistic stance. Collage is a good example of such clustering.

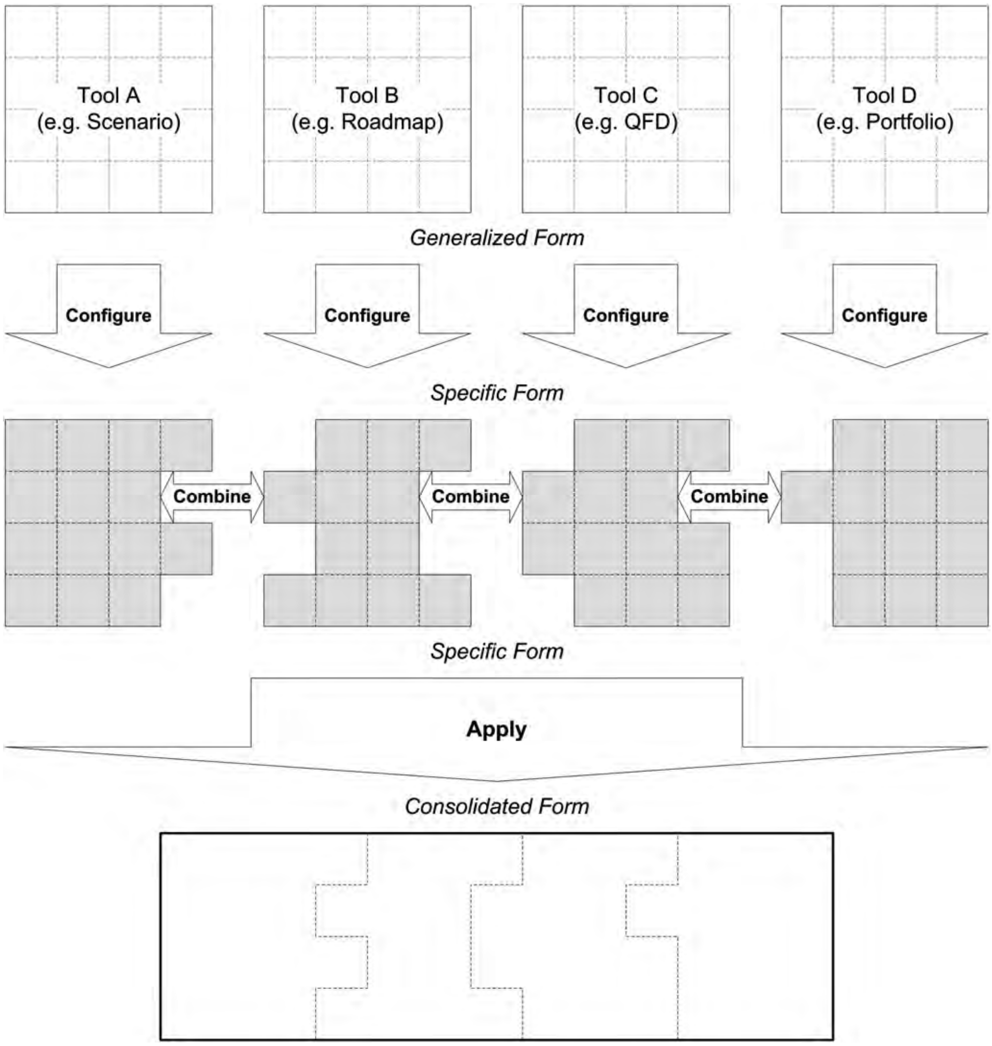

Fig. 9. Modular toolkit.
Adapted from Phaal et al. [8].

modular tools in Fig. 9 is realized through developing a set of standardized interface specifications. Therefore the guidance on how to integrate, configure and deploy a STM toolkit should, as in the case of a product platform architecture, be defined by: a set of functions, a map of functions to modules, and interface specifications that explain how modules relate to one another [62,66,67].

The other aspect of the modular principle that needs to be highlighted is, just like the modularity of the tools themselves, the output or results from the tools can be combined to form a single integrated composite visual. An example of which is presented in Fig. 10. The top layer of Fig. 10 is a flow chart that was generated from applying concept mapping. The middle layer consists of two parts, namely: a pictogram-based schedule from applying roadmapping and a capability end-state vision from using a foresight template. And finally, the bottom layer of Fig. 10 is the result of using a quality function deployment (QFD) tool to produce the ratings table along with employing standard project management tools to generate the Gantt chart.

3.6. Scalable

The sixth principle is '*scalable*' — that is, that the tools should have the ability to be employed at the different levels both within and surrounding an organization. Such a scalable hierarchy is shown in Fig. 11. For instance, a tool should be able to be used at the firm level and then move up in scale to relate the organization to the market/sectors or move down in scale to relate the organization to its portfolio/products/technologies. The principle of scalability for a STM tool comes from the concept of 'dynamic range' in roadmapping whereby the hierarchy of the roadmap readily accommodates scale in terms of the complexity of a system. "For example, roadmaps can be developed at a high-level for a business unit, mapping the evolution of a number of products and associated technology developments, and also in more detail for a specific product, mapping the evolving functionality and performance and the technology

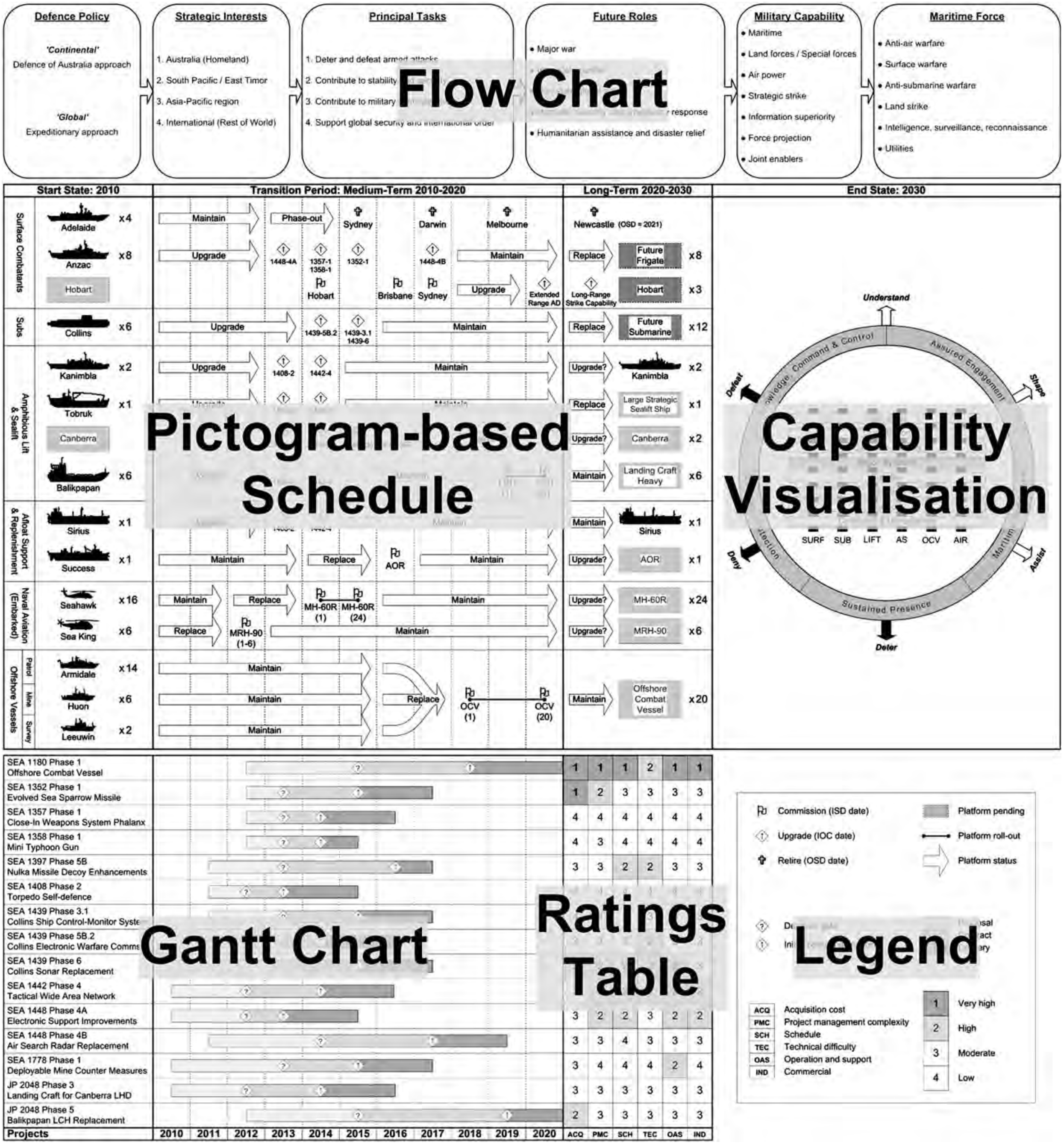

Fig. 10. Modular visual output.

development necessary to support it" [8]. Also, Phaal and Muller [31] give the example of how a sector roadmap can be viewed at the level of a limited set of sector trends with the goal of relating those trends to the relevant mono-disciplinary technology developments. Yet, underneath this high-level view are more detailed layers in the roadmap which depict hundreds of systems that play a role in the sector. Such a degree of complexity is handled by a scalable tool architecture. In addition to roadmapping, another tool that exhibits an inherent scalability are linked analysis grids [8].

3.7. Visual

The seventh principle is '*visual*' — that is, the tools should have a visual form for both their application (Fig. 12) and their resulting output (Fig. 13) with the ideal being a single page format. Franco and Montibeller [11] state that facilitative tools heavily employ

Table 5
Key concepts for a modular toolkit [8].

Concept	Description
Generalization	Most management tools need to be customized to a greater or lesser extent when applying them within an organization, depending on the business purpose and context. The question then arises as to what form does the most generic version of the tool take, and what range of specific forms is possible when applying the tool. Understanding the generic form of a tool enables the approach to be transferred between different applications, which can be quite different in their specific nature, while belonging to the same general class of problem or issue. Learning gained from one application can then be translated to another domain.
Configuration	Once the generalized form of the tool is understood, allowing the method to be translated between different application domains, then a set of design rules and guidelines needs to be established in order to customize the tool to fit the particular situation being addressed.
Combination	Most management tools cannot be applied in isolation, as they cannot alone address all of the issues in complex management situations. Tools need to be able to link to other tools, and also need to fit with business processes and systems in place.

visual displays (e.g. causal loop diagrams, cognitive maps, decision graphs, rich pictures, value trees) and "use participants' own language to represent the problem situation as well as their own judgmental preferences to evaluate decision options". This signifies the use of visual templates that are then populated with content by the workshop participants — tools are, thus, interacted with by participants through the visual medium. Fig. 12 shows two such templates that were completed using sticky notes within a workshop environment. Such visual representations of a tool form assist in communicating the differing perspectives among participants [68], provide a visual way of presenting and manipulating a problem situation [69], and enable the information exchange among the participants [69]. Additionally, according to Eppler and Platts [70], visual representations facilitate the "synthesis of information, enabling new perspectives to allow better, more exhaustive comparisons". Tools should be employed in a workshop through the use of a clear and simple visual template. From an information design perspective, "simplicity is the embodiment of clarity, elegance and economy" [71]. A visual "that offers simplicity is unambiguous and easily understood. It offers clarity — working effortlessly, devoid of unnecessary decoration. It appears deceivingly easy, accessible, and approachable, even though it may be conceptually rich. Simplicity involves distillation — every element is indispensable, if an element is removed, the composition falls apart" [71].

The visual format of the tool has an important contribution to make in terms of providing a means for contextualization. Massey and Wallace [68] note that "the most difficult part of modeling an ill-structured problem situation by a group is establishing a common framework to facilitate communication". In this regard, the visual template of a tool provides a framing mechanism. Such framing then "plays a crucial role in forming a perspective from which a situation can be understood and acted upon" [72]. Essentially, the structure of the template provides a framework within which the workshop participants can specify the correct context and make the problem 'decision-analyzable' [6]. According to Cabantous et al. [6] the aim is to create a fit between the organizational context and the decision-analysis. "It consists mainly in turning a 'big and messy' situation into a 'decision-analyzable' problem" [6]. It is about "getting the decision context right" and "structuring the elements of the decision situation into a logical framework" [14]. Weick's [73] work on sensemaking contains a very pertinent analogy that has a great degree of relevance to the situation of using visual forms of tools to support decision-making. Weick [73] states that "the task of sensemaking resembles more closely the activity of cartography. There is some terrain that the mapmakers want to represent, and they use various modes of projection to make this representation. What they map, however, depends on where they look, how they look, what they want to represent, and their tools for representation [74]. The crucial point in cartography is that there is no 'one best map' of a particular terrain. For any terrain there will be an indefinite number of useful maps, a function of the indefinite levels and kinds of description of the terrain itself, as well as the indefinite number of modes of representation and uses to which they can be put [75]".

The visual form of the tool, to be used by a group within a workshop environment, also has a strong effect on the actual engagement that takes place between the tool and the participants. Of direct relevance for ensuring tool engagement by users is the model of creative

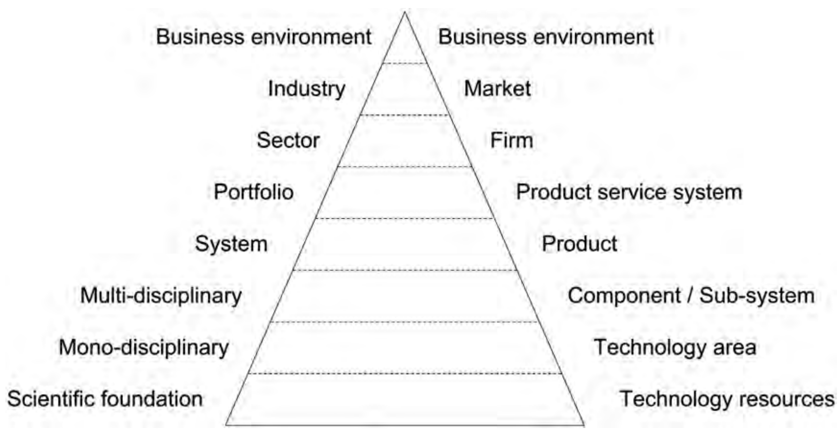

Fig. 11. Scalable.
Adapted from Phaal and Muller [31].

Fig. 12. Visual wall charts.

engagement described by Edmonds et al. [76], who were concerned with the design of interactive art systems intended for display in public locations. Their model is based on three elements, namely:

- Attractors — Those things that encourage the audience to take note of the system in the first place.
- Sustainers — Those attributes that keep the audience engaged during an initial encounter.
- Relaters — Those aspects that help a continuing relationship to grow so that the audience returns to the work on future occasions.

So, when designing the visual templates in a STM toolkit it is necessary to consider which aspects of the tools and their visual form can act as the attractors, sustainers and relaters in order to both appeal to the workshop participants and to maintain their attention until the task is complete.

There are two visual orientated tools that are worthy of special mention: concept maps and roadmaps. Concept maps, which include cognitive maps and cause maps, allow for some powerful visual analysis to be conducted within a workshop environment. Eden [77] outlines the types of analyses that can be undertaken:

- Islands of themes (i.e. clusters without accounting for hierarchy).
- Networks of problems (i.e. clusters accounting for hierarchy).
- Finding potent options.

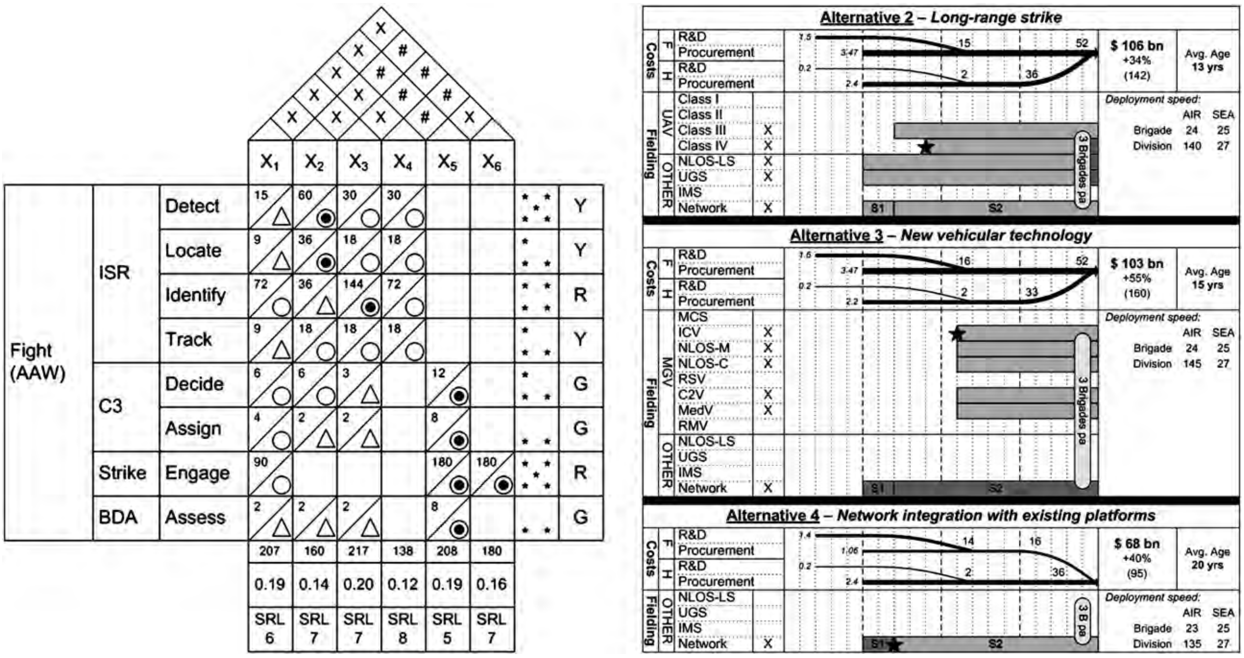

Fig. 13. Visual outputs [79,80].

- Virtuous and vicious circles.
- Central concepts as the nub of the issue.
- Simplifying the issue through emergent properties.

Having strong association with concept maps are roadmaps. In roadmapping, visualization is a key aspect of its effective practice, "both in terms of the elicitation of information from groups, and also analysis and representation for communication purposes" [33]. Phaal et al. [33] readily acknowledge that the visual nature of roadmaps is one of the main reasons for its appeal. They also recommend the use of one-page views as it "ensures that the key issues are focused on, set against the context provided by the 'big picture' view from the roadmap structure. One-page views can also be updated more easily, enabling the process to be more agile, enabling the roadmaps to keep pace with the rapidly changing business situations" [33]. However the visual aspect of roadmapping is often treated in a poor manner even though it should be a key strength. Blackwell et al. [78] have identified a number of bad design practices including cluttered/overloaded canvases containing too much content and poor organizing schemes (architecture) leading to failure in conveying a consistent message.

Finally, there is the tool output which should be regarded as a visual in its own right. This form of visual expression is for communication purposes in order to report the results of the workshop and mobilize action in the organization. Fig. 13 depicts the visual outputs resulting from the application of two STM tools. The image on the left is a QFD chart used for making trade-offs in a product's functionality [79] and the image on the right is a roadmap that portrays a number of different options and highlights the impacts associated with selecting different courses of action [80]. Kerr et al. [48] propose that specific tools such as roadmaps can act as 'boundary objects' because as visual entities they forge the links between the differing stakeholders and communicate their shared viewpoints. Star and Griesemer [81] developed the concept of boundary objects for artifacts that exist at "junctures where varied social worlds meet in an arena of mutual concern" [82]. According to Thomas et al. [83] boundary objects depend upon the co-construction of meaning and are "brought to life only through social interaction" [84] — as in the case of workshops. Additionally, "the creation and management of boundary objects are a key process in developing and maintaining coherence across intersecting communities" [85]. Not only do they help to promote "the sharing of knowledge in practice between diverse groups" [86] but also they provide a locus for communication and co-ordination [87]. To enable the visual side of STM tools to enact the role of boundary objects, it is useful to consider the aspect of 'narrative' that a tool is attempting to elicit from the workshop participants. In this regards, Rasmussen [88] points to four classical elements of stories which can be considered when designing a tool and planning its use for engagements within organizations:

- The message(s) — What is supposed to be told?
- The tension(s) — What are the driving forces of the story?
- The role distribution — Who are the actors and what roles are they supposed to play?
- The sequence of activities — What are the relationships between the events setting the story?

4. Example toolkit

To demonstrate both the integration and deployment of the seven principles consider Fig. 14 which depicts the STM toolkit that was applied in an actual commercial engagement with a multinational chemical company. This organization consisted of 19 business units with activities in 80 countries and annual revenues in the order of 15 billion Euros. The corporate strategy was to accelerate the growth in revenue to 20 billion Euros by 2020. One of the business units was given the target of increasing its revenue by 1 billion Euros, of which half would come from growth in existing markets and the other half from new markets. The toolkit shown in Fig. 14 was deployed to develop a plan for this business unit to achieve its growth target across their 14 value streams. The time horizon out to 2020 equated to four cycles in their new product development process.

In terms of the '*human-centric*' and '*workshop-based*' principles, the engagement brought together 22 participants across the business unit's domains of technical/R&D functions and commercial/marketing areas for a two-day workshop. The workshop was '*neutrally facilitated*' by a lead facilitator who guided the participants through the process and use of the tools. There was also a supporting facilitator who provided assistance where needed. The workshop was run in a '*lightly processed*' manner adopting the scheme shown in Fig. 6. In the process, the first day of the workshop consisted of a set of large group activities under the 'capture' and 'focus' steps (Fig. 6) using tools 1–2–3 (Fig. 14). The second day involved small group activities under the 'explore' and 'synthesize' steps (Fig. 6) using tools 3–4–5 (Fig. 14) and a plenary review session at the end to bring the outputs together.

As can be seen in Fig. 14 the principles of '*modular*', '*scalable*' and '*visual*' were enacted through five tool modules which spanned the business–portfolio–product levels. Each tool module had a specifically designed template and was embodied in the form of wall charts. The first module in the toolkit (Fig. 14) is the landscape roadmap which was used to capture and depict the full scope of the business unit across the dimensions of trends and drivers, value streams, manufacturing and technology resources. Clustering of theme sets allowed particular 'landmark' opportunities to emerge and be identified. The relationships across the multi-layered structure of the landscape roadmap were then mapped using a linkage grid tool. This prioritized and highlighted the key relationships between the drivers, value and resource factors in terms of their type and magnitude. The linkage grid also provided an audit trail of the group decision-making and associated rationale. The third component of the toolkit was the innovation matrix which classified the opportunities at the portfolio level in order to balance novelty and risk across new/existing markets and technologies. The final two tool modules, topic roadmap and business case (Fig. 14), provided the means to then explore the priority areas and generate outline strategies in the form of action plans. These allowed the workshop participants to describe: (i) the business opportunities in terms of market segment drivers and potential size; (ii) the key technologies and associated state of readiness;

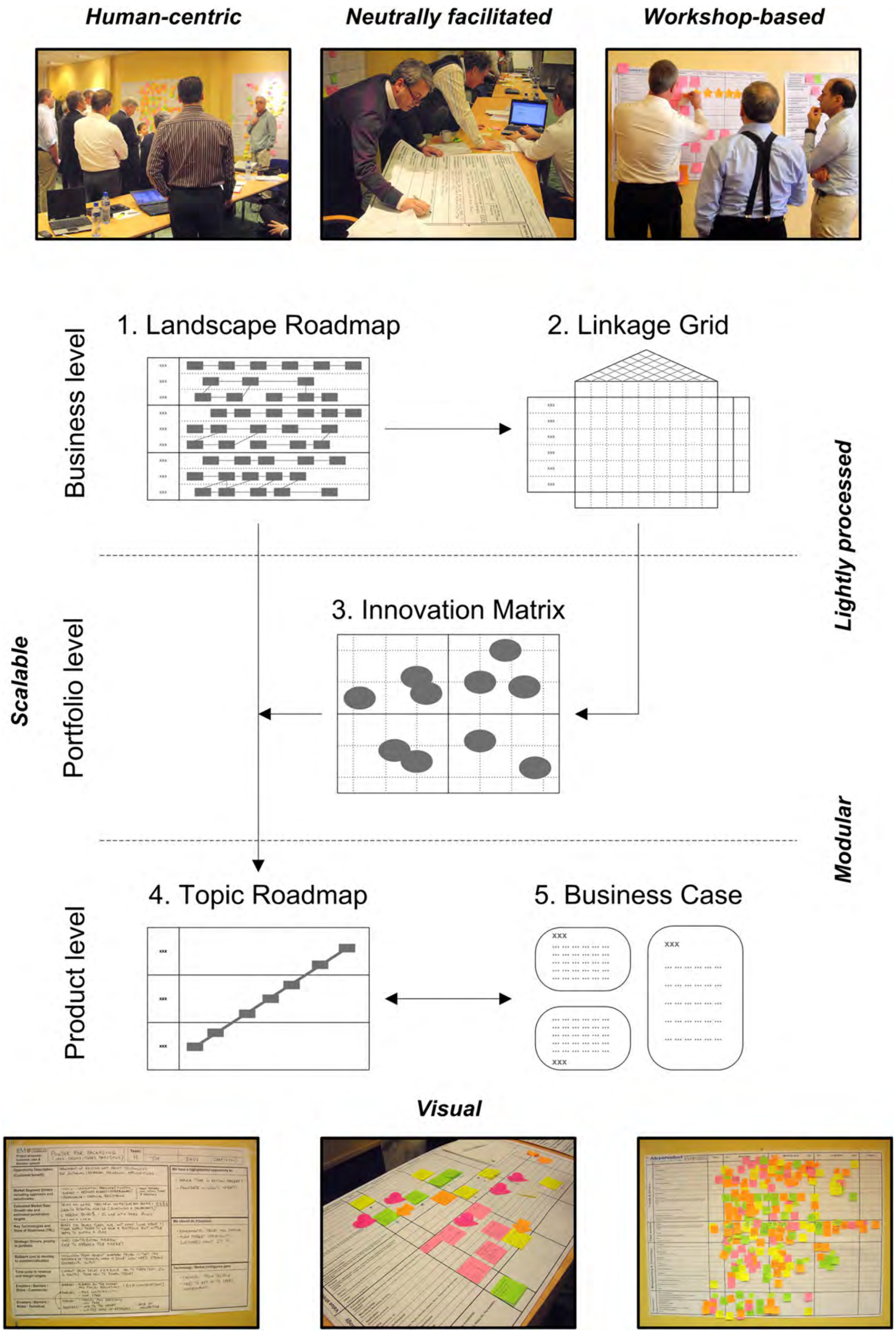

Fig. 14. Example toolkit.

(iii) the fit into the product portfolio; (iv) the commercialization effort; and, (v) the commercial/technical enablers, barriers and risks.

5. Summary

In taking a practice perspective, it has been highlighted that strategic technology management (STM) tools are, generally, employed in isolation and accompanied with a lack of consideration on how to bring them together in an integrative manner. However, in this regard, there has been a challenge put forward by Phaal et al. [8] to develop a universal toolkit that can "support a wide range of technology management decisions and processes". Their vision consists of a "minimum set of generic tools required to solve the class of problem for which they are designed, together with guidance on how to integrate, configure and deploy them". Thus in order to provide a conceptual foundation for such an industrially relevant and academically robust strategic technology management toolkit, this paper has identified seven underpinning principles that should be operationalized when developing, integrating and deploying the tools. The seven principles are:

1. *Human-centric* — The STM tools should be focused on allowing their users to participate/engage/collaborate with one another to have a strategic conversation leading to a co-created solution. The key premise of the tools is to support the social interaction and aid decision-making. This will require an appreciation of the situational factors in real-world applications by taking into account the sociological and psychological aspects of the human-centric setting.
2. *Workshop-based* — The recommended mode of engagement for deploying an STM toolkit should be through workshops as they provide the platform for group interaction through structured activities centered on the application of the tools for solving strategic problems.
3. *Neutrally facilitated* — The workshops within which the STM tools are to be applied should be facilitated from a position of neutrality whereby the facilitator should be focused on the process and not contribute to the content.
4. *Lightly processed* — The process for using the STM tools within the workshops should be applied in a lightweight manner based on the premise of 'start small and iterate fast' and allow for a degree of flexibility by not being too prescriptive. This requires adapting the macro–micro level processes, the divergent–convergent constructs, and the arrangement of the plenary–small group activities for the specific engagements.
5. *Modular* — The STM toolkit should be built in a modular fashion with the constituent tools being readily integrated with one another. Additionally, the combined final output, or product, of using the tools should also be able to have a composite form.
6. *Scalable* — The tools should have the ability to be employed at the different levels both within and surrounding an organization by employing a scalable hierarchy in order to provide a wide dynamic range.
7. *Visual* — The tools should have a visual form for both their application in the workshops and their resulting output for the purposes of reporting/communicating. The ideal being the single page format.

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