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A Hierarchical Approach to Technology Roadmapping within an RTO Environment

A proposed new digital hierarchical technology roadmapping architecture can integrate and align research activities with the manufacturing capabilities needed by industry.

Peter Osborne, Michèle Routley, and Imoh Ilevbare

OVERVIEW: Many organizations use technology roadmaps for strategic planning, and they often use workshop-based approaches to create the roadmaps. Customizing the workshop process and the artifacts used is necessary to tailor the approach to each organization's context. We describe a hierarchical architecture and software-supported workshop approach that we deployed within the UK's High Value Manufacturing Catapult. This customized approach connected technological capabilities identified within multiple organizations' technology roadmaps with different industry needs identified within sector roadmaps. This development process provided a framework to facilitate discussion between academia and industry and to build a clear set of narratives linking the development of new technologies with industry challenges. By digitizing the workshop outputs in a common database, we integrated multiple narratives dynamically, supported different views for the various stakeholders involved, and facilitated reuse of roadmapping elements generated in different workshops.

KEYWORDS: Strategic planning, Technology roadmapping, Roadmap, Roadmapping

In 2011, Innovate UK established the Catapult network to provide access to world-class R&D facilities and expertise that would otherwise be out of reach for many UK businesses. Catapults are physical centres with cutting-edge R&D infrastructures, including hubs, laboratories, testbeds, factories, and offices, as well as technical experts that prove and adopt breakthrough products, processes, services, and technologies. The Catapults occupy nodal positions within innovation ecosystems, bringing together key players across the innovation chain, linking academia and industry, and bridging the "valley of death" described by Marczewski (1997). The Catapults comprise an important part of the UK's "knowledge" infrastructure as Research & Technology Organizations (RTOs) within their focus areas. In fulfilling this role, the Catapult research centres must match industry requirements with opportunities provided by academia and set up suitable technology pipelines to deliver the solutions the industry needs.

The High Value Manufacturing (HVM) Catapult was the first of the new Catapults; it brought together seven manufacturing research centres (High Value Manufacturing Catapult 2021) with different technology competencies and areas of application. When constructing their roadmaps, the HVM Catapult must interact with a diverse range of internal and external stakeholders (Figure 1). This requirement creates a complex problem if, as part of its five-year plan, the Catapult plans to integrate and align the roadmaps across the complete ecosystem to demonstrate value for money from investments made in its research activities.

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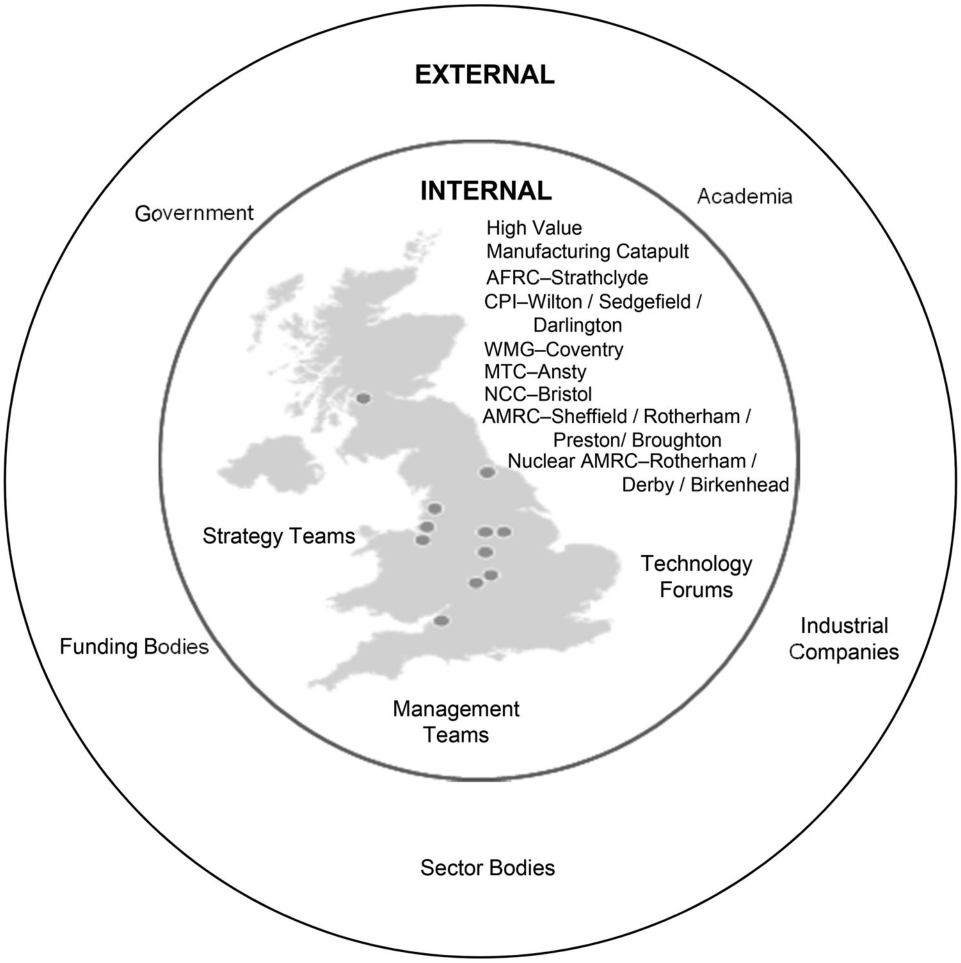

FIGURE 1. Internal and external stakeholders involved in the HVM Catapult roadmapping activities

We describe the development and customization of an integrated hierarchical roadmapping approach. We used action research to investigate the development of several roadmaps in workshops, which provided an improved architecture for the resulting roadmaps that could be captured in a database. Through clear narratives, these roadmaps highlight how groups of technologies must come together to address industries' future needs.

Literature Review

We conducted our literature review on roadmapping, workshops, and customization.

Roadmapping

Technology roadmapping has become a widely used management technique for supporting technology and innovation management at the company (Gerdsri, Vatananan, and Dansamasatid 2009), sector (Amer and Daim 2010), and governmental levels (Lee and Park 2005). Experts attribute the initial development of the technology roadmapping concept to Motorola (Willyard and McClees 1987).

Roadmapping is a flexible approach that typically requires customization to achieve specific objectives for an organization and its stakeholders (Phaal, Farrukh, and Probert 2004). Fast-start, workshop-based roadmapping approaches often use a landscape chart to capture participants' perspectives in a time-based, multilayer format (Phaal, Farrukh, and Probert 2010). The typical three main layers are configured to answer "why," "what," and "how" within the context of the roadmapping activity (Phaal and Muller 2009).

A roadmap provides a structured visual representation of strategy that brings together a variety of perspectives. However, the flexibility of the approach can cause problems when attempting to link together different roadmaps to provide a more complete picture of the requirements across many different technology areas and industrial sectors. These linkages are particularly important where solutions must be brought together from multiple organizations: a danger exists that the required solutions may not come together in a timely manner, and the required intent will be lost in translation between organizations. In this scenario, the roadmaps' architect must carefully design the architecture of the roadmaps to ensure the intent of each item transfers between roadmaps consistently and important details do not get lost.

Workshops

The development of good roadmaps requires the involvement of key stakeholders and groups. Identifying the appropriate participants, particularly in workshops, is a key consideration during the planning phase (Gerdsri, Vatananan, and Dansamasatid 2009). These stakeholders, however, will often represent diverse perspectives (Kerr, Phaal, and Probert 2012) and use their own distinct language. Without careful facilitation and a clear architecture for the roadmap, the inputs gathered during a workshop might require considerable work to process into a set of useable outputs that all stakeholder groups can agree to (Christensen et al. 2019). Differences in language used by workshop participants must be well understood to capture their true intent.

According to Phaal and Muller (2009, p. 39), "A key benefit of the [workshop] approach is the communication associated with the development and dissemination of roadmaps, particularly for aligning technology and commercial perspectives, balancing market 'pull' and technology 'push.'" Tension exists between requirements set by the commercial application of a solution and the opportunities provided by the technical development, which respectively drive development and constrain the application (Figure 2).

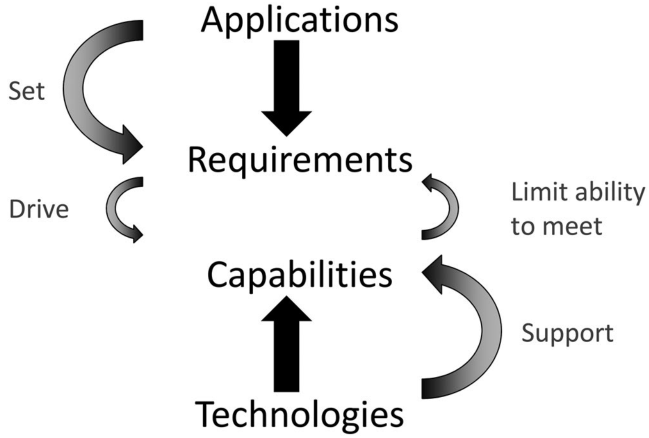

FIGURE 2. Roadmapping helps to communicate how industry needs can be met by technological development

This tension manifests itself in several ways. Two of the most important considerations that must be addressed when customizing the roadmapping process are aligning the terminology used between the different groups involved in a roadmap's creation and managing the differing expectations around the timing of the creation of new capabilities, against when companies require them. The use of artifacts such as the structured architecture (layers and timeframes) of the roadmapping canvas help address these considerations.

Customization

Phaal and Muller (2009, p. 41) observed that "Roadmaps can cover a tremendous 'dynamic range,' in terms of scale and complexity of the system . . . [and] can be viewed at the level of a limited set of sector trends with the goal of relating these trends to relevant mono-disciplinary technology developments."

The challenge when attempting to link together roadmaps is to be able to find the most relevant technology details relating to a sector trend. A good example of this challenge is the integrated US electronics industry roadmaps created by the National Electronics Manufacturing Initiative (NEMI) (National Electronics Manufacturing Initiative 1998) and discussed by Kostoff and Schaller (2001). These system-driven roadmaps connected many existing roadmaps from different branches of the electronics sector.

The challenge when attempting to link together roadmaps is to be able to find the most relevant technology details relating to a sector trend.

NEMI's objective in taking this approach was to align scientific efforts across diverse roadmaps and align them with electronic industry trends. NEMI's approach allowed for the alignment of different industry roadmaps within the electronics sector, but the roadmaps were not dynamically integrated and were statically fixed in time. An update to one of the roadmaps didn't automatically update the content on the linked roadmaps. If done effectively, the electronics industry could use the ability to dynamically integrate roadmaps to develop a narrative to show what and when development activities need to be conducted in one part of the sector to provide capabilities in another.

Kerr, Phaal, and Thams (2019) described the customization of the University of Cambridge S-Plan process within the Lego Group. The authors examined how the specific process activities could be applied within the organizational environment. The underlying question driving their reflection was: if the Lego Group were to adopt the roadmapping method and roll it out across their internal groups, what would a suitable process look like?

Case Study

As a national organization that operates across multiple industrial sectors and incorporates seven research centres, the HVM Catapult's complexity may provide useful insights for complex, dispersed technology-intensive companies. One of the study's coauthors is the HVM Catapult's lead architect for roadmapping and has led the creation of roadmapping for the last eight years. The other authors helped the HVM Catapult initiate integrated roadmapping from a consultancy support perspective. This study provided a unique opportunity for action research reflections to be made, evaluating the effects of customizing the roadmapping approach to achieve the HVM Catapult's aim of improved communication.

We studied what was required to customize roadmapping for the HVM Catapult. Our study had three main objectives:

1. To better align RTO programs with industry needs;
2. To create the possibility for sharing and aligning technology efforts toward big industry goals; and
3. To enable exploration of the connections among roadmaps.

Given the complexity of the many organizations involved, it was imperative that we define a process and artifacts suitable for the complex task of effective communication between academia and industry. Creating a hierarchical approach was key to link effectively the many different technology areas with the range of industrial sectors they support.

Historical Centre-level Roadmapping

Prior to our study, the research centres within the HVM Catapult had created a range of top-down and bottom-up roadmaps by bringing together the various industrial, academic, and governmental stakeholders in each industrial sector. These roadmaps took different forms because they were designed to meet specific needs associated with the target stakeholder groups. Consequently, the research centres struggled to integrate the different roadmapping activities due to differences in the terminology and architecture used across functional perspectives at different ends of the technology-readiness scale.

To create an effective technology pipeline, the HVM Catapult needed to create a vision of the different sectors' future requirements that would integrate the technology opportunities currently being developed by the different research centres. This objective required a complex matrix-style interaction between the sectors and technologies (Figure 3) to enable sharing and alignment of technology efforts towards big industry goals, while simultaneously maximizing the benefits of each development program.

Method

We conducted a participatory action research case study in which the authors were engaged as facilitators in the design and implementation of roadmapping in the HVM Catapult. The authors gathered information by participating in meetings and workshops. They took notes, which provided the data we used to improve the method for the next planned series of workshops.

Terminology challenges

The process many of the research centres used to create their initial roadmaps followed Phaal, Farrukh, and Probert's (2010) "fast-start" roadmapping approach. In this approach, the why, what, and how questions help identify inputs in the following layers:

- Why—business/market drivers
- What—products/services
- How—technologies

Because the stakeholders involved in the HVM Catapult roadmapping process had different organizational and professional backgrounds, the terminology caused some confusion. One example is the use of the term "Product or Service" in conjunction with the "what" statement. The intention of the statement is to describe "what" the organization will do to meet the needs and drivers described in the "why" statement.

Sector / Technology	Aerospace	Automotive	Construction	Energy	Food & Drink	Healthcare
Automation						
Composites						
Design						
Digital Manufacturing						
Electronics						
Joining						
Metrology						

FIGURE 3. The matrix-style interaction challenge faced when creating technology roadmaps

Engineers from within the aerospace sector will refer to aircraft or their subcomponents when talking about their products. If we ask technology providers who supply manufacturing solutions to the manufacturing industry what their products are, they will describe their solutions (machine tools, cutting tools, software). The aerospace engineers will see these as the technologies required to create their products.

Due to this confusion, we had similar inputs in different roadmapping layers depending on who the predominant participants taking part in the workshop sessions were.

Designing an Integrated Approach

The HVM Catapult used the outputs from the different roadmapping and strategic planning activities to select 12 strategic objectives covering the full range of sectors and technologies the research centres address. These strategic objectives form the basis of the HVM Catapult's five-year plan and are referenced by the individual research centre strategies. One desired outcome of a new integrated roadmapping approach was to create a clearer narrative that describes how the various technology development activities occurring across the network help to meet these strategic objectives.

Customization Requirements: Hierarchical Architecture

The first stage in consolidating the various top-down and bottom-up roadmaps previously created across the HVM Catapult focused on determining the architectural requirements of the solution needed. We held a "Roadmapping Roadmapping" session (Phaal 2019), in which a group of internal HVM Catapult stakeholders developed and formalized their vision for the outputs of the roadmapping and explored the steps needed to create the shared vision for these roadmaps. The stakeholders came from different user groups representing suppliers and customers.

The "Roadmapping" session achieved two important goals. First, it generated a shared vision for roadmapping and articulated participants' common needs. Second, it drew out several themes, including the desire to communicate clearly, the ability to demonstrate impact through clear technology-industry linkage, and the ability to develop the roadmaps through a cocreation process engaging multiple academia and industry stakeholders.

Organizations must absorb the knowledge surrounding an innovation and build their capability and their supplier base to roll out and exploit those innovations by a competent workforce.

This workshop identified several desired outputs from the roadmapping process:

- Industrial sectors' requirements, such as capabilities over time within the national manufacturing context;
- Opportunities presented by current and emerging technologies;
- Gaps and overlaps of proposed research projects compared with industry requirements; and
- Alignment of the HVM Catapult strategic objectives and the research centres' technology development plans.

The process also highlighted the need for a tiered approach to the roadmaps, to be able to identify the capability requirements for each of the sectors the HVM Catapult supports and to link them with the various technological possibilities available across the research centres. Aligning industry needs with opportunities provided by academia helps ensure that the research centres develop and make capabilities available in a timely manner to fulfil industry requirements at the time of need.

The roadmapping process requires diverse perspectives from all the key stakeholders represented. At different points in a roadmapping workshop, some participants' opinions might be more qualified than others, so the workshop facilitators need strong facilitation skills. For example, an industry attendee can identify the needs of the business they represent, while a technology specialist can provide insight on their specialist area.

Initiating Integrated Roadmapping

Many of the research centres had already modified the fast-start approach to elicit more specific inputs to their roadmaps beyond the basic why, what, how structure. These modifications helped ensure relevance to workshop session participants.

Building on these modifications, we developed the sector-level and technology-level hierarchical architecture that allowed the linking of the different roadmaps; provided a common thread from fundamental competence building through to the dissemination of the knowledge into industry; and ultimately led to the creation of impact (Table 1). Industry capability is not merely an output of an innovation activity conducted within an RTO. Organizations must also absorb the knowledge surrounding that innovation and build their capability and their supplier base to roll out and exploit those innovations by a competent workforce.

Four technology teams within the HVM Catapult—Additive Manufacturing (AM), Composites Manufacturing, Digital Manufacturing, and Metrology—used this trial approach, as did one of the sector-level Aerospace strategy teams, to develop roadmaps in their field. Each of these activities included mixed groups of technically and industrially focused stakeholders with differing roles and responsibilities. The trial process was iterative due to the desire to link the two levels of roadmaps and involved the stages (Figure 4).

TABLE 1. The architecture used to link the HVM Catapult sector roadmaps to the supporting technology roadmaps

Sector Roadmap		Layer	Technology Roadmap	
Why?	Manufacturing Trend and drivers Programme opportunities	1		
What?	Industry capability	2	Industry capability	Why?
How?	Innovation outputs	3	Innovation outputs	What?
		4	Innovation challenges	How?
Resources	Resources	5	Resources	Resources?

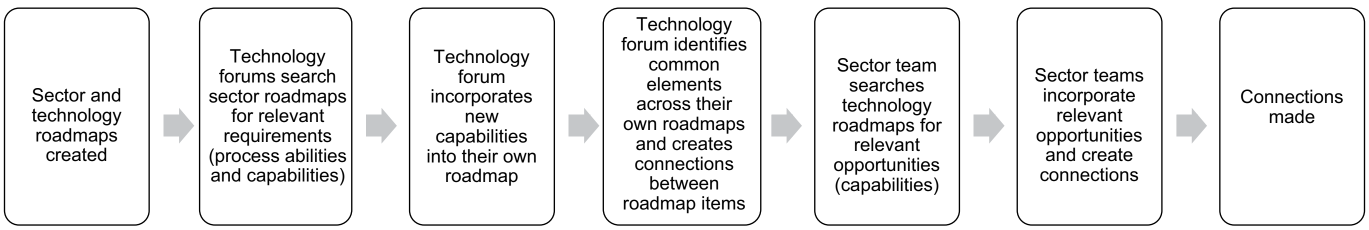

FIGURE 4. Process flow to establish connectivity between the pilot roadmaps

In these first trials, we used the labels Research Outputs and Research Questions to describe the products and services and technology categories previously used. One unexpected discovery was that within the HVM Catapult there is no universal acceptance that the activities conducted fit under the banner of "Research." Workshop participants achieved consensus that the activities all fell under the broader heading of "Innovation," so we modified the terminology accordingly.

Sector-Level Roadmaps

The sector-level roadmaps use the HVM Catapult's strategic objectives as their "vision" of the desired future state for the sector.

These vision statements are supported by several intermediate manufacturing trends and drivers derived from relevant industry roadmaps that identify the intermediate steps required to achieve the roadmaps' vision. Where an external program opportunity exists that might provide an opportunity for the introduction of a new disruptive technological solution, we captured and displayed the information below the trends and drivers as a second level of "why." This information captures the external products and services that will fulfil the trends and drivers in the level above.

The second layer of the roadmaps shows the industry capabilities—that is, the application of the technology solutions that bring about the desired change in the performance of a process—that need to be demonstrated to achieve this future state. To achieve this change within industry, organizations will need to develop the workforce and supplier base, alongside the technology solution. One goal of the roadmaps is to help identify what non-technological developments are required to facilitate this change.

The innovation outputs that must be developed will sit below the industry capabilities. The innovation outputs are the outputs of the research centres' development projects.

Technology-Level Roadmaps

The technology-level roadmaps use a vision of the future state based on versions of the industry capabilities on the sector-level roadmaps that are relevant to the technology.

Several intermediate trends and drivers support these vision statements. Industry capabilities required by the sectors that use this technology support the trends and drivers.

The second layer of the roadmap shows the innovation outputs that the HVM Catapult will need to develop. The innovation challenges that the research centres need to answer to underpin the capabilities sit below the innovation outputs.

The final level of both sets of roadmaps show the key resources needed to be brought in to enable these activities to occur. We defined key resources as new equipment and capabilities the HVM Catapult needs to provide the required innovation outputs.

Introducing Software

One objective of this study was to show a clear narrative linking activities to relevant sector trends and drivers, and

One goal of the roadmaps is to help identify what non-technological developments are required to facilitate change.

hence show the underpinning potential and alignment of technology development activities across multiple roadmaps. To achieve this goal, we needed to integrate the roadmaps with narrative threads of activity clearly highlighted. We digitized workshop outputs using SharpCloud, a visual business collaboration software for strategic portfolio management that allows the dynamic integration and visual representation of the complex relationships within a database and permits multiple people to collaborate on the same dataset simultaneously. SharpCloud also allows the data to be filtered in many ways in real-time to tell the required narrative. This functionality has several benefits in situations where technology solutions are applicable to multiple sectors, thus a need exists to use data from one roadmap to tell multiple narratives. To share data across multiple roadmaps effectively, the HVM Catapult had to develop the architecture and language described in this paper.

Discussion

Our initial evidence suggests that refining the questions asked at each level helped the groups maintain focus on the intended type of outputs. We reduced the instances of items placed in the wrong category or duplication of responses in the innovation challenge and innovation outputs categories.

The lack of acceptance of the term "research" required further work to find a suitable description for the categories that describe the creation of new knowledge at the lower levels of the HVM Catapult roadmaps. After some discussion amongst the stakeholder groups, we replaced "research" with "innovation" and modified the descriptions slightly.

Customizing the approach also revealed further areas for development around the process used to determine the ownership of the outputs describing research activities. The ownership of the outputs could lie with the customer, who will ultimately take its use forward and implement its further development, or with the supplier, who will be responsible for their creation. Within the RTO environment, the customer-supplier construct is more complex than an industrial customer-supplier relationship because the success of the research activity is harder to predict, and the required date and significant elements of the specification may not be accurately known at the point of capture.

During this process, the UK's Aerospace Technology Institute (ATI) asked the HVM Catapult to develop its materials and manufacturing roadmap. ATI has adopted the aerospace roadmap developed within this activity, and the items captured within it will influence the institute's future funding activities within the manufacturing sector. This influence is particularly important given the step change in propulsion technology currently taking place within aerospace toward alternative fuels and electric propulsion technologies to meet future emissions targets. These technologies represent a significant change for the aerospace sector. In addition, the identification of future developments that must take place is essential if the UK hopes to maintain its global position within the aerospace manufacturing sector.

Development work for some of these technologies, particularly around battery and motor technologies, is already in place in other sectors; therefore, one benefit of the hierarchical approach adopted in this activity has been to show how innovation activities initiated in a different sector can be of use to the aerospace industry.

Currently, the focus within the process has been on identifying innovation outputs required to support the future trends and drivers within the sector. This activity has led to the integration of capability requirements across several different technology areas.

The approach we describe is a development of that outlined in the European Industry Research Management Association (EIRMA) working group report on the practice of technology roadmapping (European Industry Research Management Association 1997) (Figure 5). The key difference between the EIRMA generic roadmap and the approach taken here was the deliberate decision made to split the sector-focused elements from the technology-focused elements. The matrix-based approach taken within the HVM Catapult facilitated the integration of technology roadmaps with multiple sector roadmaps.

On the HVM Catapult's aerospace sector roadmap, the data are displayed digitally in a series of views within SharpCloud (Figure 6). In this roadmap the narrative is broken down into several paradigms that relate to different aircraft development activities, with this element relating to the optimization of today's products.

In this view, participants identified "net-shaped processes" as one of the enabling industrial capabilities that must be demonstrated to improve the "buy to fly" ratio of aerospace components. To develop this capability, workshop participants identified several innovation outputs (bottom) as necessary to provide the capability. Taking "In-process quality control" as an example, we might identify it as being related to the particular process being used to produce the components. Traditionally, this relationship might have been the end of the narrative; however, in this case we can explore this narrative further by taking advantage of the digital tool being used to display the roadmap and explore the next layer. In this example, we can see that "In-process quality control" exists not just in this roadmap but also in a second roadmap (Figure 7).

The second HVM Catapult AM Roadmap shows "In-process quality control" within the context of its use within this roadmap. In this view, we filtered the content to show one of the strategic themes identified by the technology team to tell a clear narrative about a development thread within their roadmap. This view uses a coarser timescale view that recognizes that in the early stages of a roadmap's development, the exact timing requirement may not be known. Breaking the timescale of the roadmap into short-, medium-, and long-term

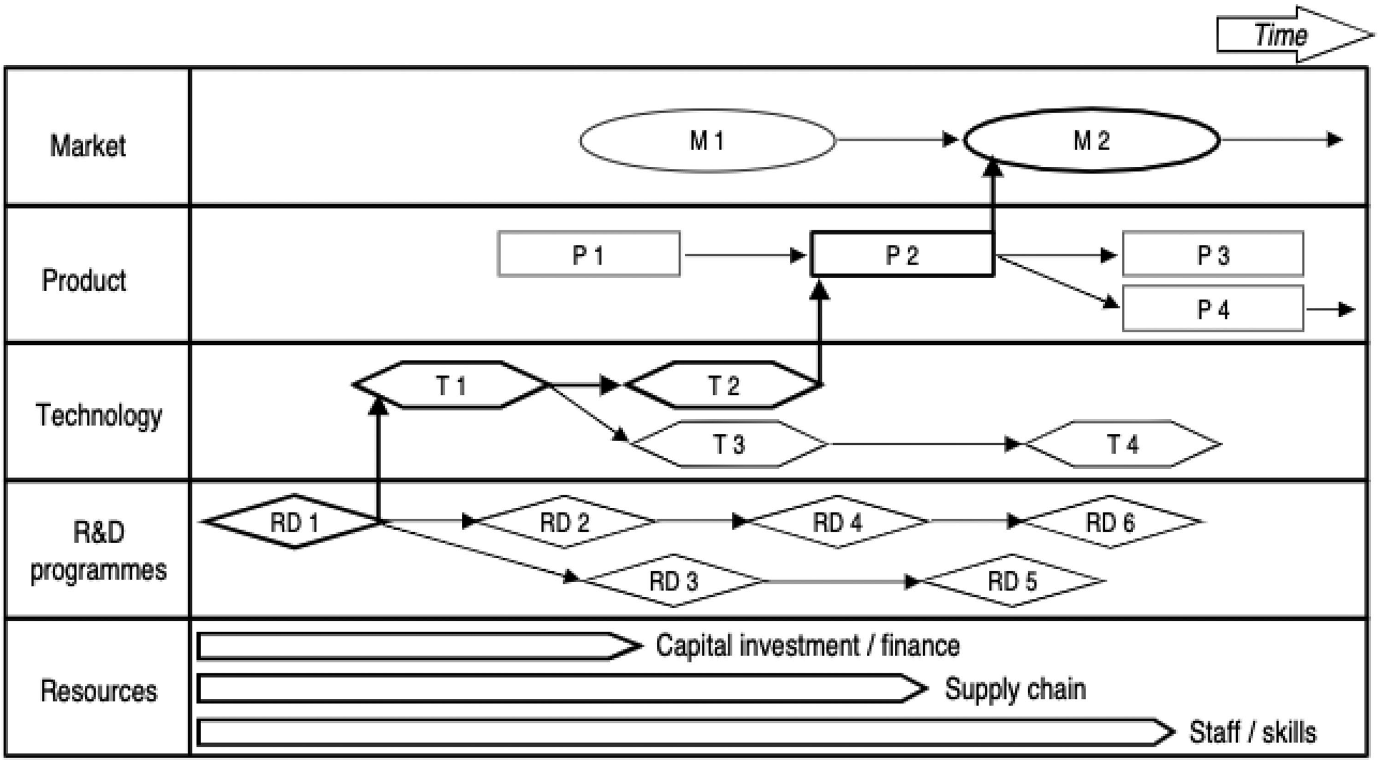

FIGURE 5. Generic roadmap structure (Probert 2003, adapted from European Industry Research Management Association 1997)

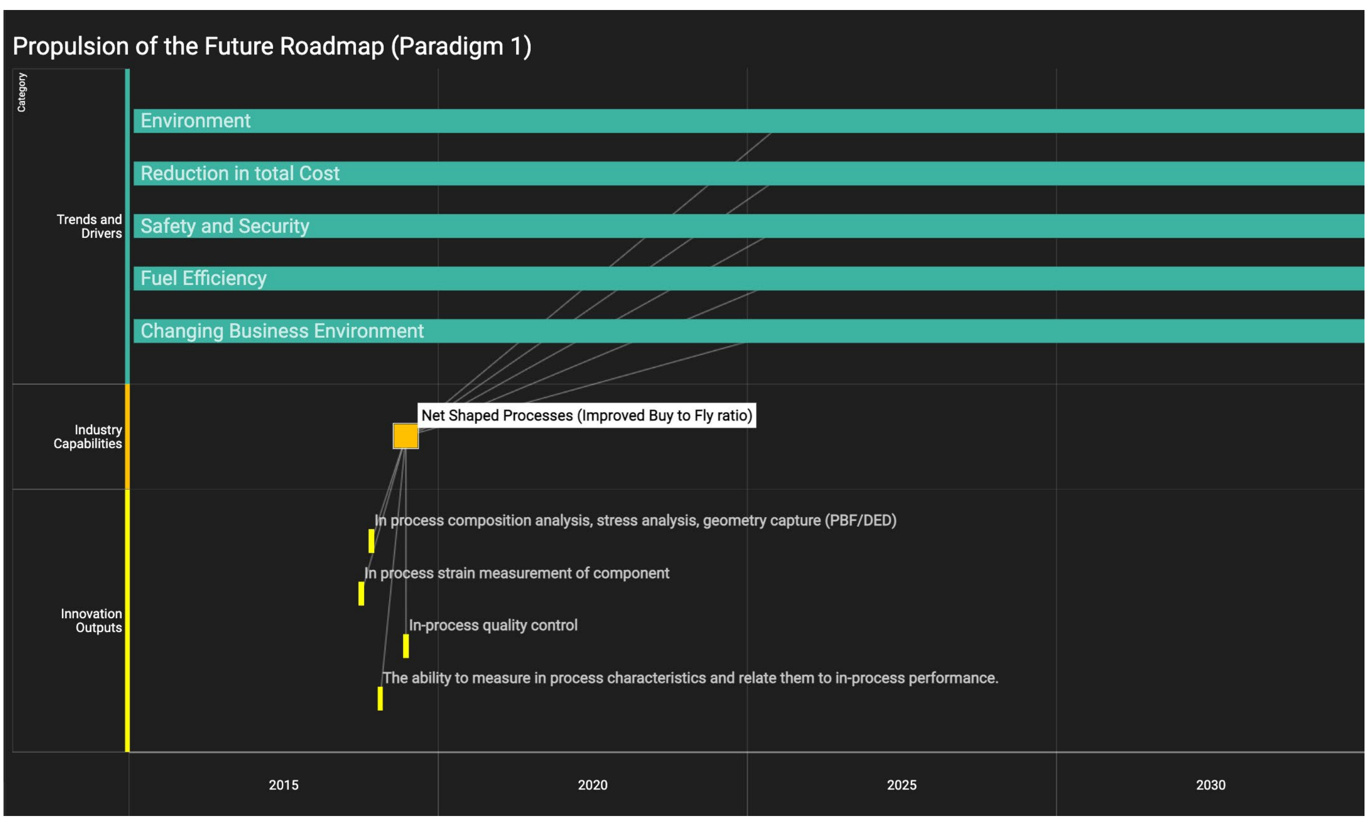

FIGURE 6. Example view from the HVM Catapult Aerospace Roadmap

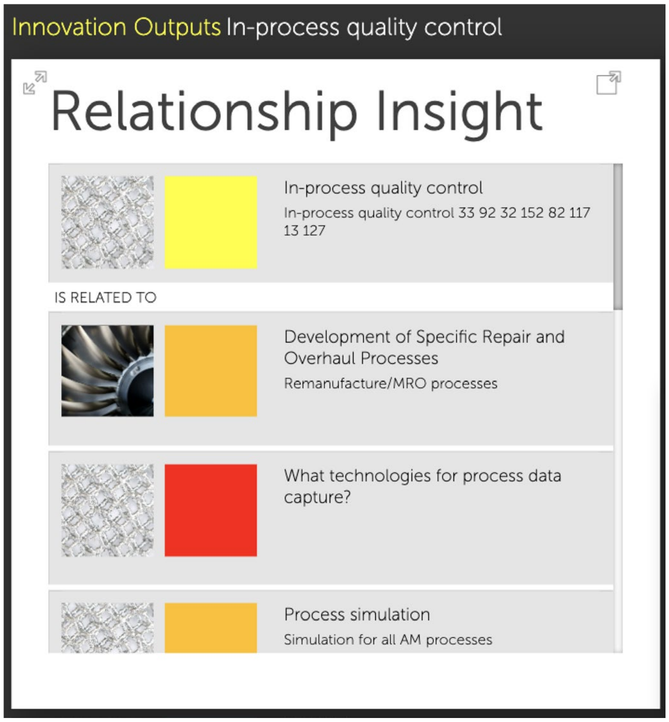

FIGURE 7. In-process quality (expanded view) showing relationships within multiple roadmap stories

allowed the roadmap participants to assign more quickly an approximate timescale for a requirement that could be refined later.

Through this example, we can see how a thread of development can be followed from the identification of a requirement at the sector level through to the fundamental questions that must be answered to provide the solution. Alternatively, the identification of a technological opportunity can be linked to the potential applications in which it may be used. By separating the two perspectives of the roadmap, we have provided a means in which innovation outputs can be shown to solve challenges in multiple sectors and/or how challenges rely on a range of fundamental knowledge coming from different technology areas to solve them. This process has also helped to ensure that we have the correct people at each stage of the roadmapping process who come armed with relevant knowledge at the right level of granularity to input into the roadmap.

Conclusion

We developed a new digital hierarchical technology roadmapping architecture to integrate and align research activities with the manufacturing capabilities needed by industry. Our approach allows for the creation of narratives that include both industry pull and technology push. The SharpCloud software enabled the filtering of data to create the perspective required by the end user, and the integration of different themes highlighted where technology developments in one sector could be aligned in other sectors with similar requirements. Our customization of the technology roadmapping process has helped clarify the roadmapping approach and has removed uncertainty regarding what was required from workshop participants. We plan to continue to develop and refine our approach; it will be rolled out for the HVM Catapult's sector and technology teams to use in their roadmapping activities. Our approach is now being implemented and integrated across other technology themes. We have demonstrated the potential value of our approach for other RTOs or complex sector/national level organizations interested in highlighting the value of their research programs by aligning them across multiple development programs in different sectors.

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