High Value Manufacturing in the UK: A Study of its Challenges, Opportunities and Emerging Technologies

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Abstract
The High Value Manufacturing (HVM) Catapult is a collection of manufacturing research centres designed by the UK government to help foster and develop manufacturing in the UK. The Landscape project will inform the manufacturing strategy adopted by the UK Government and its HVM Catapult. The intention is for these results to continue to inform strategy and public policy development in the UK. The Landscape project endeavoured to explore current and future environments by identifying the trends, drivers and challenges in UK manufacturing and the technologies and their related capabilities that could be at the leading edge of manufacturing in 2025. This paper outlines the process that was undertaken to develop the current and future global 'landscape' of manufacturing. The project identified dozens of capabilities that UK firms could develop to be competitive in manufacturing, given the challenges and emerging technologies facing the industry. It also identified national competencies that could be developed to foster the growth of industrial commons in the UK. This paper will present the project's major outcomes, highlighting the opportunities in UK manufacturing.

Keywords*: High value manufacturing, Trends, challenges & opportunities*

1 Introduction

In many countries, including the United Kingdom (UK), there is renewed interest in the role of manufacturing in national economies [1]. In these countries, policy makers have been given more latitude to foster technology development and increase their industrial competitiveness. Globalisation, the rise of developing nations and the increasing pace of technology change and innovation have changed previously strong industrial sectors and put new demands on firms. New technology development programs and initiatives are needed to keep pace with the shifting industrial environment. Concurrently, there is renewed interest and discourse in research and its ability to address these needs and challenges.

The UK was once the premier industrial nation in the world. Since the industrial development of other nations, particularly the US, the BRIC countries and other East Asian nations, the first mover advantages of its development have dwindled. The UK now faces a more open, global industrial market with many competing nations.

Furthermore, opening up of its industrial markets and a shift in industrial activity to low cost countries has reduced manufacturing in the UK, forcing a personnel shift to the support activities in the value

chain and further back in the product development cycle.

To increase activity in its industrial sectors, the UK needs to foster innovation and technology development. Policy makers are particularly focussing on policies that support job growth, innovation and increased activity in the manufacturing sector.

To support research, development and innovation in the UK, the UK Government developed the Catapult program. Overseen by the Technology Strategy Board (TSB), the Catapult program consists of seven centres designed to assist with the development of technology and increase innovation in the UK.

The HVM Catapult is one centre this initiative has given rise to. The HVM Catapult is a network of seven manufacturing research institutes from across the UK and is designed to bridge the gap between business, academia, research and government [2, 3].

Understanding these areas of the industrial environment can assist to provide more informed, tailored and targeted policy in the area. It provides areas of manufacturing to focus on, an understanding of the promising technologies to invest in and an understanding of factors that prevent the full economic and social benefits of innovation to be realised.

This paper explores a strategic framework that was developed by the Institute for Manufacturing, University of Cambridge for the HVM Catapult. The framework identified the trends and drivers and challenges for manufacturing in the UK. The framework also explores national competencies - strong support industries that enhance the nation's competitiveness in a given industry.

2 Background

2.1 *Technology development*

The environment of an industry can be decomposed into a multitude of perspectives and categories. Porter [4], for example, breaks down the structural analysis of an industry into: the power of buyers; the power of suppliers; the ease of entry; the threat of substitutes and rivalry amongst existing firms. For the purpose of technology development and innovation, an industry environment can be seen as consisting of:

- Trends & drivers;
- Challenges;
- Market needs and opportunities;
- Industry needs;
- Emerging sciences and technologies; and
- Barriers and enablers.

This structure for an innovation environment is borrowed heavily from the work from Phaal *et al.* [5], who use a similar structure to perceive and breakdown the R&D and innovation environment through Technology Roadmapping (TRM).

2.2 *The UK's industrial background*

Following the industrial revolution the UK continued to develop its manufacturing industries with innovations and production capability across a wide range of sectors. Global markets were developed often with overseas production capability. Many early brands still have resonance today in some parts of the world.

Towards the end of the nineteenth century the US, Germany and other European countries rapidly extended the capability and scale of their industries but the UK continued to be the home to many world leading companies. This broad industrial profile and capability continued through to the middle of the twentieth century despite wars and significant social upheavals. By the 1960s however, relative performance was faltering, there was continuing industrial unrest and a growing belief that the future no longer lay with manufacturing. The discovery of oil in the North Sea substantially strengthened the Sterling which further dimmed the prospects for manufacturing.

The 1980s saw beginning of deregulation of financial services, the growth of mobile telecommunications and computing and a widely held view that the UK was moving towards a 'post-industrial', service-based society. A sustained period of growth through the beginning of the 21st century reinforced this view despite increasing concerns expressed in some quarters. It was not until the financial debacles of 2008 that serious concern started to be widely expressed about the balance of the economy and the potential importance of manufacturing.

2.3 *Manufacturing strategy in the UK*

The lack of concern about manufacturing in the UK is reflected in the fact that between the 1970s and 2003 there was no formal government strategy towards manufacturing. There had been initiatives of various kinds which influenced manufacturing but these typically had an emphasis on so called 'horizontal' measures which were designed to

provide a sound financial, educational and infrastructural foundation for enterprise of all kinds. The fashion across the political spectrum was to rely more heavily on free market policies than almost any other industrialised nation.

The 2003 strategy, though not radical did seek to draw together policies towards manufacturing and subsequent publications in 2005 and 2007. These early initiatives were dramatically strengthened by the arrival of a Secretary of State for Industry who initiated a major refocusing of government interest towards manufacturing. This focus lead to substantial public investments in key industries, the establishment of industry leadership groups and close attention to the links between industry and the internationally successful UK science base. One of the key outcomes was the recognition that despite growing engagement between universities and industry a critical gap had opened up between the identification of new technologies and their tailoring for commercial application. A new model of Technology Innovation Centres - later renamed Catapult Centres - was proposed which received cross-party support leading to a formal announcement in 2010.

This project endeavoured to understand the environment one of the centres, the High Value Manufacturing Catapult, would be operating. This paper reports some of the results of this project.

3 Method

3.1 *The Landscape Framework*

A novel methodology was adopted to explore the multi-dimensional nature of the UK's manufacturing environment. The process engaged with and integrated the responses of senior level industrialists, researchers, academics and civil servants as well as information from past research and reports.

3.2 *The Phases of the project*

The project was conducted in five phases, with engagement with the HVM Catapult members, the TSB and the acceptance of submissions continuing in parallel throughout the project. The project phases can be seen in Figure 1.

The process began by exploring the past research and policy in manufacturing, including the TSB's emerging technologies study [6], the IfM's database of roadmaps, publically available roadmaps and the HVM Catapult's Business Plan [2, 3, 7]. The results of this exploration were then used as the basis of a series of structured engagements with senior level industrialists, researchers, academics and civil servants.

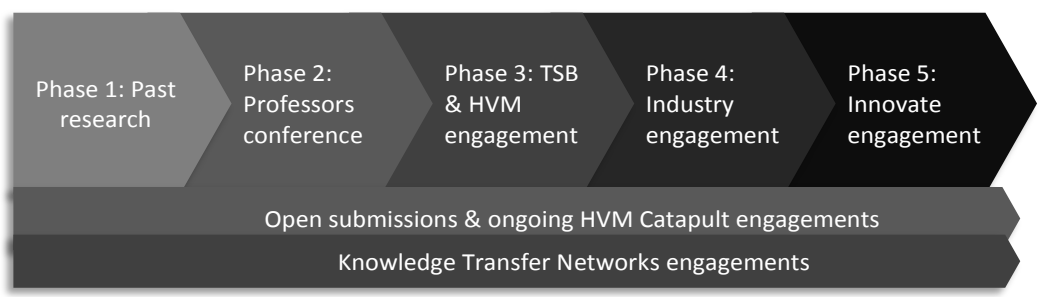

Figure 1: Project Phases

The first of these engagements was an annual Manufacturing professors conference, held in London. At this conference, attendees were given the trends and drivers that were found during the exploration of past research. They were asked to add any trends and drivers they saw as affecting the UK's manufacturing industry and amend or challenge any trends and drivers already identified.

Phase three of the project saw an engagement with the TSB and the board of the HVM Catapult to review and amend the trends, drivers and challenges for UK manufacturing. The group explored the needs of the industry that were required to address those trends and drivers as well as any other needs they saw as important to the industry.

Phase four constituted a series of engagements with industrial personnel in the UK. People we invited from the upper echelons of firms who were important participants in UK manufacturing. In these workshops, participants were asked for their views on the:

- trends and drivers;
- challenges;
- the most important processes and systems for the UK over the next 15 years; and
- what were the most promising emerging science, engineering and technology innovations that would address the trends and challenges.

Representatives from the HVM Catapult's research centres were present at each industry engagement.

Phase five of the project focused on the final two questions asked of industry personnel: what processes and systems will be important in the future and what are the most promising emerging technologies and innovations for UK manufacturing. These questions were explored in detail by civil servants, including representatives from the Department for Business, Innovation and Skills (BIS), the Engineering and Physical Sciences Research Council (EPSRC) and academics at the forefront of research in manufacturing. This engagement had a particular focus on minority reports in emerging technologies. These minority reports were the opinions of experts and captured what technologies could create new paradigms in manufacturing.

In parallel to these five phases there was ongoing engagement with the HVM board and TSB submissions on the topic were accepted. Also ongoing were a series of workshops with the UK's Knowledge Transfer Networks (KTNs), who's unique perspective and expertise were captured and included in the analysis.

These engagements used a range of workshop and interview techniques to identify key factors in each of the industry's dimensions: trends and drivers; challenges; market and industry needs; emerging science and technologies; and barriers and enablers.

Each engagement added to the detail of the industrial 'landscape' and each provided a valuable and unique perspective. An overview of the contributions made by the various stakeholders to the process can be seen in Figure 2.

Submissions were also accepted throughout the process and their contributions to the key fields recorded. These submissions offered the insight of academics, researchers and industrial personnel who could not attend the engagements.

The information gathered from these workshops were recorded in databases. These databases allowed the depth and detail of information acquired at the workshops to be recorded for analysis. The databases can be recalled and examined for the supporting information and evidence behind the analysis and can also be easily updated.

The findings from these engagements were recorded and were cross-examined for consistency. All the findings were reconciled and triangulated to generate the final results, which were then prioritised and summarised for reporting purposes. That is, the results from the workshops were consolidated and the most prevalent contributions to the results extracted and summarised.

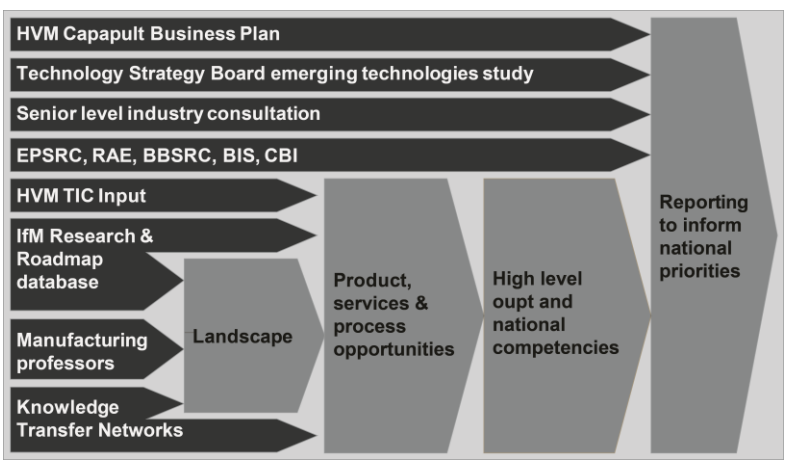

Figure 2: Input flows in the Methodology

4 Results

The framework produced many results of interest to business, developers of public policy and academia. This section outlines a selection of the results from the project.

4.1 *Trends and Drivers*

Through the engagements, participants identified what they thought were the UK manufacturing's major trends as drivers. The HVM Catapult engagements voted on the potential impact of these trends and drivers. These were then cross-checked with the frequency these were raised in the industry engagements, the innovation engagements and the submissions. The resulting trends and drivers, ranked by impact, are shown in Table 1.

The *Increasing cost and scarcity of materials* was a common concern for participants consulted throughout the project. Added to this the trends of *Aging workforce and skill shortages* and the continuing strong competition from the East, a challenging future environment for the industry is illustrated.

The trends of *High cost of factors of production* further affects the ability of UK firms to compete. The combination of this with the *Increasing cost and scarcity of materials* and *Skills shortages* continue to affect the ability of UK firms to compete on cost differentiation.

Structural changes to the industry are also prevalent in the trends and drivers. *'Hollowing out' of the UK base supply chain* and *Power and opportunity continues to move to the East* suggest the continuation of the evolution of the manufacturing support services in the UK that has been witnessed over the last 20 to 30 years.

Table 1: The Major Trends and Drivers of HVM

Trends and drivers	Importance
Increasing cost and scarcity of materials driving importance of security of supply, use of fewer materials (including water) and outputs, as well as more reliance on renewable resource-less energy for all	Very High
Ageing UK workforce, skill shortages (and into 2015+), with low mobility	Very High
Need to influence and adapt to evolving government policy, tax and regulations to maximise competitiveness (including as regards emissions and sustainability)	Very High
Power and opportunity continues to move East and beyond, whilst increasing transport costs encourage repatriation/on-shoring	Very High
Government priority support for R&D and innovation	High
Emergence of new industries (e.g. photonics, renewable energy) with strategic opportunities for global leadership by UK businesses particularly in multi-disciplinary areas	High
'Hollowing out' of the UK based supply chain and increasing threats to SMEs from a combination of skills and finance shortages, together with global OEM procurement policies	High
Affluence increases pace of change	Moderate
Access to credit and funding (including VC) and political impact on policy timeframes	Moderate
Rise of the 'digital economy' and impact on 'traditional' products, services and processes, as well as creation of 'new' demands	Moderate
High cost of factors of production in the UK	Moderate
Growing, ageing population increases demand, waste and imposes challenges for health, social care and food	Moderate

4.2 *Challenges for HVM*

The major challenges as identified throughout all phases of the project are listed in Table 2. These challenged were identified by academics, researchers, civil servants and industrial leaders. The HVM Catapult research centres, industrial representatives, researchers and civil servants voted on the importance of each of the challenges, creating the ranking shown in Table 2.

The two challenges marked as extremely important, that of *Constructively influencing the evolution of Government economic, taxation and regulation policies* and *Building necessary skills and attracting them to Manufacturing*, map directly onto some of the more important trends and drivers. They demonstrate that industry is concerned and actively contemplating the challenge and the alternatives if the challenge is met or not.

Innovation and barriers to innovation is a theme common to many of the challenges. *Bridging the innovation gap/ 'valley of death'*, *Creating new business models to exploit innovation and capture value* and *Maintaining and enhancing the innovation capability of the UK economy* all have a strong focus on innovation. They demonstrate the current importance being placed on innovation in the UK and the fact that many see it as a promising route to growth and for dealing with current economic troubles.

The two challenges that focus on the *efficiency of the UK economy* and the *innovation capability of the UK economy* also demonstrate a common thread in the project. These emphasise the importance of the UK economy as a whole for the manufacturing industry. This thread exemplifies the interlinked nature of economies and, while innovation may be seen as a vehicle for growth, the manufacturing sector is dependent on other sectors remaining strong to provide innovation.

Finally, the last two challenges shown in Table 2, *Exploiting new opportunities in the digital economy* and *Exploiting new markets associated with aging populations*, are focused on capitalising on the changing nature of markets. These challenges demonstrate progressive thinking and a desire to capitalise on new markets.

Table 2: The Major Challenges to HVM in the UK

Challenges	Importance
Constructively influencing the evolution of Government economic, taxation and regulation policies and ensuring ability to adapt, exploit and conform as these policies evolve.	Very high
Building necessary skills and attracting them to Manufacturing	Very high
Bridging the innovation gap/ 'valley of death'	High
Creating new business models to exploit innovation and capture value	High
Responding to the increasing cost of energy, particularly exploiting the low carbon market, and reducing usage of and securing materials	Moderate
Maintaining and enhancing the efficiency of the UK economy	Moderate
Maintaining and enhancing the innovation capability of the UK economy	Moderate
Building and sustaining the UK SME base and their role in the value chain	Moderate
Attracting investment to manufacturing in the prevailing economic and cultural climate	Moderate
Exploiting new product, service and process opportunities available in the digital economy	Moderate
Exploiting growing markets associated with aging population, particularly health care	Moderate

4.3 *National Competencies*

The National Competencies identified by the framework can be seen in Table 3. These were developed by representatives from the seven research centres in the HVM Catapult, civil servants, researchers from eight of the UK's Knowledge Transfer Networks and the IfM, University of Cambridge.

Table 3: UK National Competencies that can help develop HVM competitiveness in the UK

Strategic Themes (competency cluster)	National Competency
Increasing the global competitiveness of products, services & processes	Biotech & biological processing
	Process engineering & capability development across food, pharmaceuticals & chemicals
	Design & manufacture for small-scale & miniaturisation
	Systems modelling & integrated design/simulation
	Automation & human/machine Interface
	Large-scale 'plug & play' manufacturing
	Exploiting intelligent systems and autonomy
	New processes for scale, economy & low energy
	Understanding design & manufacture of formulated products
Improving product, service & process performance	Smart, hybrid & multiple materials
	Real-time data capture/processing & new non-destructive testing techniques
	Development and application of advanced coatings
	Personalisation/batch of one
	Electronics Integration
Developing products, services & processes faster	Flexible, adaptive manufacture
	Combining product development steps in parallel development
	Tool-less (rapid & additive) & one-shot manufacture
Securing UK manufacturing against scarcity of energy & other resources	Energy storage, management & security
	Design & manufacture for sustainability
	Through-life design & manufacture
	Design & manufacture for light weighting
Building new business models to realise value	Distributed Manufacture
	New business models & skills to support HVM
	Safety Engineering & risk management

The national competencies were grouped into five distinct clusters. These clusters were termed strategic themes. Many of the other results from the project were mapped against the strategic themes.

Although it is not indicated in Table 3, national competencies can increase the UK's capacity in more than just one of the strategic themes. Furthermore, the first four classifications all rest within the fifth group of building new business models to realise value. Indeed, it is transformation at this level that seems to have produced some of the most competitive companies today. Amazon, for example, is one such company that has performed very well by transforming the retailing sector using the internet. It could be a source of strong competitive advantage if such transcending business structures could be

formulated in UK manufacturing. Such structures change the competitive nature of an industry and give companies a strong competitive edge.

Many of the national competencies listed in Table 2 are trans-sectoral within the manufacturing industry. Flexible, adaptive manufacturing, for example, applies to many sectors of industry, including automotive, consumer goods, construction supply and heavy machinery. The trans-sectoral nature of the national competencies is why they can be important for industry to develop. Furthermore, their trans-sectoral nature demonstrates that if the national competencies are developed they can contribute heavily to firms' competitiveness in a range of different areas.

Another theme to note in the national competencies is the emphasis on processes. Many of the different competencies listed focus on process based technologies. This focus demonstrates the areas those involved in the project saw as key for developing competitive advantages within UK manufacturing.

A summary of the results from the framework were reported in *A landscape for the future of high value manufacturing* [7].

5 Discussion

5.1 *Trends, drivers and challenges*

A positive sign for the project is the prevalence of government action in the trends, drivers and challenges. This prevalence suggests that the government does have a large role to play in the industry. Furthermore, it suggests that action has the potential to be very supportive or very damaging to the industry. Informing and focusing government policy could help these trends, drivers and challenges to positively affect the industry, supporting the need for informative projects such as this. It is evidence that properly informed policy is very important to the industry.

The trends, drivers and challenges seem to bear a gloomy outlook for the industry. However, this outlook is not as negative as it first appears. Many of the trends, drivers and challenges indicate possible opportunities for the industry. As *Affluence increases the pace of change*, for example, firms with a competitive advantage in change are positioned to thrive.

Several of the trends and drivers can be map onto the challenges (and of course the reverse is also true). This is due to the related nature of the questions: trends and drivers often are the environmental elements that pose challenges.

However, it is the differences between the trends and drivers outlined in Table 1 and the challenges outlined in Table 2 that demonstrate a potential shortcoming in the way the UK's manufacturing industry is viewed. It is a potential concern that some of the trends and drivers that pose risks to manufacturing in the UK are not reflected in the challenges. By ranking the trends and drivers by importance, it demonstrates their potential impact on the manufacturing environment. The challenges then should address many of these trends and drivers. If this is not the case then it could indicate there is a problem with either the trends and drivers or - and more likely - the challenges people perceive face the industry. For example, energy is considered a moderate challenge for the industry, compared to the other challenges, but the closest corresponding two trends/drivers include *all* material and resource costs and scarcity.

Challenges arise from more than just trends and drivers, so a similar concern is not warranted when a challenge is not reflected by the trends and drivers. This is the case in instances of sudden change as these are events, sudden turn-points or, as it is called in TRM, tipping points. This however, should be examined on a case by case basis. The restrictions placed on oil exports by OPEC countries in 1972/73 is an example of such a sudden change to the operating environment and presented a challenge that was not perceived solely through trends or drivers.

Complex relationships also exist between the trends and drivers and the challenges and they do not have to be reflected as a one-to-one. The trend/driver of *affluence and its effect of the pace of change* (which in this case envelopes both current affluence levels and the effects of future affluence levels, particularly in the east and other developing nations), for example, has a complex relationship with the challenges. Instead of addressing rates of change directly, academia, government and industry seem to view this as a series of challenges for innovation. *Bridging the gap/ 'Valley of Death'* and *Maintaining and enhancing the innovation capability of the UK* are two examples of the challenges participants saw as important that reflect this trend/driver.

The perspective shift between a trend/driver and the challenges they subsequently see as arising from it is an insight into how people in the field function. To decompose such an issue and identify points of

influence (called leverage points by Meadows, 2008) require experience and a detailed understanding of industry. Not only this unique insight, but the ability for this perspective shift could be useful in solving problems and developing policy and strategy.

Trends and drivers are not the only source of challenges. Unforseen challenges can arise from unforeseen and unconsidered events. Other techniques will have to employed to understand these possibilities. Thus the list of trends and drivers can be an indicator of challenges, but will not necessary detail all currently perceived challenges for the industry.

5.2 *National competencies*

The national competencies demonstrate how the researchers, academics, civil servants and industrialists involved in the project view the industry. The competencies cut through the industry in many different ways, they overlap and a large number could be applied to the one product or firm. The multifaceted nature of the national competencies exemplifies the potential multitude of grounds for competition as products become more integrated and complex.

The national competencies also have a strong emphasis on design. As production moves to low cost countries, manufacturing sectors in nations like the UK have begun to focus more on the support services for production, such as design. There are two possible explanations for design's prominence in the national competencies. The first is that it is prominent because it is the focus of the industry and at the fore of people's thinking. The second is that there is a potential for design to serve as a major source of competitive advantage. It is likely however, that both are to a degree true. It is because design can serve as a source of competitive advantage - by providing unique products or processes by which to produce the products so as to compete on differentiation, cost or both - that it strongly present in the thinking of those involved in the project. This is also true for research and development, another prominent support activity in the national competencies.

The national competencies were areas participants identified that the UK could build on to support manufacturing. These areas are similar to the idea of industrial commons, but focus on particular areas of industry. If these areas are developed, they would become national competencies - areas of excellence that the UK is known to have a special aptitude for over and above many other competing nations. Participants saw the competencies listed in Table 3 as the most important areas that the UK could develop to enhance its manufacturing capabilities. The methodology triangulated the varying perspectives of the project's participants and identified these areas as the most important for the UK to help:

- research and development;
- emerging technologies to market (that is, capture value from new technologies);
- integrate current technologies to create new products; and
- decrease cost in production through innovative processes

Participants saw that by developing these fields of expertise in the UK, manufacturing in the UK would have the opportunity and the support it needs to expand and grow and be more competitive globally.

It is proposed that these areas of possible national competency would assist manufacturing growth by not only providing work in the areas themselves, but also supporting manufacturing activities in a number of other manufacturing sectors. By having the knowledge and expertise locally and readily available, firms can use them to develop their own capabilities increasing their competitiveness and that of the UK's manufacturing and the overall competitiveness of UK manufacturing.

6 Conclusions

6.1 *Intention of use*

The framework used to identify some of the elements in the HVM environment and a selected summary of its results has been present. The framework, custom-made for this particular project, was successful in identifying prevalent, exigent elements of the UK's HVM environment. It is hoped that these results can be used to inform public policy as well as research and development and innovation in HVM.

Given the time restrictions and resource restrictions for the project, the framework appears to have delivered what it was designed to deliver. A wide range of previous research and stakeholders were consulted and positive results were produced.

Two improvements to the process are suggested. Firstly, a wider group could have been consulted for the process. While representatives from dozens of industrial firms and eight of the UK's Knowledge

Transfer Networks, many civil servants, academics and researchers were consulted in the project, there were many more who could have valuably contributed to it. Secondly, that more time could have been given to allow more submissions. Had more time been scheduled for the project, perhaps a wider group of stakeholders could have been consulted.

The trends and drivers and challenges that arose from the framework are complementary in many aspects. However, neither one of these should be considered in isolation and both play an important role in the development of policy. Challenges are present in the trends and drivers that is not at the fore of industrial thinking. Furthermore, many of the trends and drivers could give rise to other challenges not yet considered. The benefits of considering both trends and drivers and challenges in parallel seem to be just, if not more so, important than simply 'drawing the links' between the two.

Many of the national competencies identified in Table 3 also address several of the challenges identified in Table 2. This reflects the general systems nature of the national competencies. Being more process and technology utilisation capabilities the national competencies impact many different facets of manufacturing and industry. It is the general impact of national competencies that would give the UK a competitive advantage in manufacturing, if it were to develop them.

One possible way of obtaining sustainable value for the UK economy is to develop quasi *industrial commons* in these areas. If the UK develops these commons into national competencies it will attract the business, become known for it and in turn attract some of the best minds in the area, essential for many of the national competencies listed. The prominence of design and research and development in the national competencies show both their potential to be sources of value for the UK economy and that there is much focus on these in industry already.

6.2 *Further work*

Further work could investigate if the framework could be applied in other countries or in other industries. The information collated using the framework provides strategically important information for public policy. Similar benefit could await governments and industries if it were applied in different situations.

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