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Capability management of manufacturing research centres: challenges and opportunities

Abstract

This paper is the first to investigate capability management of manufacturing research centres within the High Value Manufacturing Catapult (HVMC). The HVMC was established to address the valley of death by bridging the gap between industry and academia in order to drive the UK's economic and technological growth. However, the current literature does not fully recognise capability management of manufacturing research centres, and hence overlook its link with operations management and strategic management within research centres' environment. Regarding technology capabilities, manufacturing companies usually adopt their own measurements or assessment tools such as Technology Readiness Levels (TRL) or Manufacturing Readiness Levels (MRL) to track their technological progression. These tools, however, are not sufficient to devise important capability management practices due to research centres' unique operating characteristics. It is evident that standardising such practices within the HVMC is vital, and this drives the need of developing a new capability management framework.

Keywords

capability management; manufacturing research centres; valley of death; technology capabilities; maturity; readiness; people; equipment; project; framework

1. Introduction

The UK manufacturing sector relies heavily on the research centres when overcoming the valley of death, i.e. "*to help turn ideas into commercial applications by addressing the gap between technology concept and commercialis*ation" (HVMC, 2018). The valley of death is a major challenge to the world especially the UK. According to the Global Innovation Index (co-published by Cornell University, INSTEAD and WIPO), the UK achieved 5th place in the Global Innovation Index 2019, compared with

4th in 2018 indicating a drop. This is mainly because UK scored lower in the five areas: institutions, human capital and research, infrastructure, market sophistication, and business sophistication, all areas where "research centres" are undoubtedly key contributors.

In this study, the research centres examined are part of the High Value Manufacturing Catapult (HVMC). These centres are "*not-for-profit, independent organisations which connect businesses with the UK's research and academic communities*" (HVMC, 2017). Table 1 shows 27 key technology capabilities across seven research centres forming the HVMC. These technology capabilities are ranked by their commonalities which indicate that the first 15 technology capabilities play a significant role in the UK manufacturing sector.

"Table 1"

However, our analysis results indicate that there is no standardised capability management approach to differentiate and benchmark among different research centres. This hinders the HVMC from developing and improving its capabilities to support strategic growth. A standard approach of capability management is critical when considering megatrends and how fast the industrial needs change in this technology-driven world (e.g. supply chain disruption due to COVID-19). In this paper, capability is defined as "*the capacity of an organisation to purposefully create, extend, or modify its resource base*" (Malik & Kotabe, 2009) to "*turn great ideas into reality*" (HVMC, 2018). Without fully recognising their own strengths and weaknesses, research centres may undertake projects that are not compatible with their capabilities, or do not create any strategic value to both themselves and the sector. Hence, this study addresses two research questions:

RQ1: What are the challenges of capability management within manufacturing research centres' environment?

RQ2: How manufacturing research centres could manage those challenges?

To address the research questions, this paper is organised as follows. Firstly, literature review and face-to-face interviews are reported in Section 2 and Section 3 respectively. Section 4 highlights the major findings, and Section 5 discusses the managerial implications. Finally, conclusions and future work are presented in Section 6.

2. Literature Review

2.1 Overview

Resource based view and dynamic capabilities are the two most well-known theories of capability management in the literature. Resource based view theory dictates how organisations should manage both of their tangible and intangible resources as key capabilities to excel (Montealegre, 2002) while dynamic capability theory emphasises the creation of competitive advantage "*to analyse the sources and methods of wealth creation and capture by private enterprise firms operating in environments of rapid technological change*" (Teece et al., 1997). Dynamic capabilities theory is applicable to both new ventures and established companies (Zahra et al., 2006). However, the same investigation in the research centre environment is lacking.

2.2. Identified research themes and their sub-themes

To understand the capability management literature, 74 key management and manufacturing management papers were included with a focus on technology capability and maturity. Following Webster and Watson's (2002) approach, six main research themes (RTs) are identified: Challenges (RT1), Maturity (RT2), Capability (RT3), Strategy (RT4), Decision Making (RT5) and Academia & Industry (RT6). Tables 2 – 7 describe each of the six RTs and their sub-themes (ST).

2.2.1 RT1: Challenges

"Table 2"

Table 2 shows that both external and internal challenges identified are mainly relevant to industrial environment. Some negative impacts of internal challenges on businesses are highlighted as losing a market position, financial loss, etc. However, these challenges and impacts are not described in the context of research centres. Nevertheless, one of the industrial challenges, to "*continuously fit their capabilities to environmental changes*" (Paiva, et al., 2008), is found relevant to research centres. Therefore, like industrial companies, research centres also need to adapt their capabilities to all market changes.

2.2.2. RT2: Maturity

"Table 3"

There is a lack of standardised definition of maturity in different sectors. The manufacturing sector where the HVMC sits in is not an exception as shown in Table 3. In fact, each organisation may have its own maturity capability model specific to its unique operating characteristics (Hauser, 2014). While some capability maturity models (e.g. CMM, P-CMM and CMMi) look advanced and comprehensive, their application is restricted to individual companies having specific industrial requirements. Similar to challenges, the maturity of research centres is not clearly defined / standardised, hence, no maturity model is found applicable to research centres.

2.2.3. RT3: Capability

"Table 4"

Capabilities are known to drive competitive advantages which determine competitiveness, market share, and organisational performance. For instance, dynamic capability theory has attracted more attention as it advocates the development of business models to sustain competitive advantages which create financial returns (Teece, 2018). This theory is also useful to support strategic management which helps correlate a firm's operating characteristics with its prospects in a particular competitive context (Winter, 2003). However, it does not consider the unique operating characteristics of research centres in the HVMC where technology (as one main form of capabilities) transfer is pursued *between* research centres and Industry to improve the sector's competitiveness. In contrast, dynamic capability theory urges that such a transfer, under an industrial setting, should be enabled *within* companies to develop one's own competitiveness. Another theory, Resource based view, assumes that resources must be heterogeneous and immobile to help the firm gain competitive edge. This greatly contradicts the purpose of research centres in the HMVC which aims to provide external businesses access to key resources and thus bridge the valley of death.

While hard aspects such as technology / equipment play a significant role in the manufacturing sector, soft aspects such as teamwork, co-operation, and communication are also vital. Even with the most advanced technology, a company is unable to fully utilise its potential without competent staff (i.e. people). Therefore, this highlights the importance of both human capability and technology capabilities.

2.2.4. RT4: Strategy

"Table 5"

Table 5 shows that strategy is useful in dictating the mechanisms that companies need to sustain. This includes the practice of managing capabilities which must be aligned with the company's strategic goal to create competitive advantage. In other words, having a well-defined strategy shows that a company understands its market position and knows how to exploit and explore their capabilities. This reinforces the link between strategic management and capability management. Without a proper strategy, organisations struggle to recognise their own capabilities, hence scatter their efforts (Fuchs, et al., 2000). This challenge is also relevant to research centres as they need to grow themselves and the sector.

Nevertheless, like maturity and capability, the current literature does not examine the strategic management of research centres given their unique operating characteristics . Hence, no existing strategic management framework is found applicable to research centres.

2.2.5: RT5: Decision Making

"Table 6"

When a company expands, and its capabilities grow so do the decision factors it needs to consider. While both Resource based view and dynamic capability theories provide guidelines over some important decisions (e.g. strategic, technological, financial, etc.), one significant element, the characteristics of a decision maker (e.g. experience, personalities, risk attitude, etc.), is overlooked (Newey & Zahra, 2009). Depending on the situational complexity and uncertainty, decision makers' characteristics may affect decision making processes and outcomes. Hence, various operations management techniques have been developed to improve the decision making process objectivity and reliability (St John et al., 2001) as companies do not always have control over all decision factors.

Regarding capability management, characteristics of a good decision maker are discussed mostly from an industrial point of view ((Thompson & Walsham, 2004), (Marsh & Stock, 2006)), rather than research centre's perspective. Moreover, no standardised decision making processes are specific to research centres and this further complicates the issues of defining and measuring maturity, managing capabilities and developing strategies in research centre environment.

2.2.6. RT6: Academia & Industry

"Table 7"

This RT is important to examine the gap between Academia and Industry which helps bridge the valley of death. Table 7 shows that although the role of R&D plays a significant role in bridging the gap, it mostly refers to the collaboration between University and Industry while overlooking the role of Research Centre. Hence, researchers tend to investigate challenges encountered by universities, e.g. university technologies are deemed as immature or irrelevant to businesses (Graff et al., 2002), universities prefer to seek industrial sponsorship which is more flexible but in smaller scale than government support (Guerrero et al., 2017), and conflicting objectives usually exist between public and private organisations (Fini et al., 2019). Although universities and research centres share some of these challenges, they do have different operating characteristics .

Nevertheless, R&D hubs often act as the bridge between the academic and industrial sectors (Graff et al., 2002) and this explains the influential role of research centres in supplying knowledge to drive businesses' innovation (Spring et al., 2017). Having said that, the literature does not offer useful guidance over capability management in the context of research centres. The role of research centres and their capability management practices should be better recognised in order to bridge the valley of death and drive both innovation and commercialisation performance of the UK.

2.3 Review findings

Four major findings suggest that the literature does not fully recognise capability management of research centres. The first one is a lack of standardised definition of what research centre is and what it does. Research centres are often regarded as universities ((Leifer et al., 2001), (Manning et al., 2008)), Technology and Innovation Centres (Hauser, 2010), Science Parks (Lecluyse et al., 2019) or Technology Transfer Offices (Good et al., 2019). Since research centres have unique operating characteristics, they must be properly defined. This, however, remains an issue in the UK manufacturing sector.

The second finding is a lack of standardised definition of maturity which is essential to capability management of research centres. Literature often defines maturity in relation to readiness and this encourages the use of Technology Readiness Level (TRL) or Manufacturing Readiness Level (MRL) assessment approaches. (Tetlay and John, 2009) clearly differentiated maturity from readiness: "*Maturity is therefore regarded as a part of readiness, the system must first be fully 'mature' before it can be 'ready' for use*." Moreover, (Nuclear Decommissioning Authority, 2014) mentioned that "*Readiness refers to time. Specifically, it means ready for operations at the present time*" and it is also "*context specific*" (Seablom and Lemmerman, 2012), (Ward et al., 2017).

While TRL/MRL approaches can indicate the level of development a given technology capability has achieved, they do not tell if the research centres can master that technology capability. In other words, those approaches only assess "*what has been achieved at a specific time*" but do not illustrate "*how it has been achieved*", i.e. the maturity of a specific technology capability. Although some maturity models exist (e.g. CMM, CMMI, SE-CMM), they are specific to software development companies rather than manufacturing research centres.

Since the operating characteristics of research centres and maturity are not well-understood (the first two findings), the third finding explains a lack of standardised procedure to define and measure their capabilities. Most capability management frameworks are found to be specific to industrial companies. Although some capability performance indicators are discussed for universities which are the closet counterpart to research centres, those indicators (e.g. student satisfaction) are not relevant to research centres. Despite the fact that research centres in the HVMC share the common goal of bridging the valley of death, there is no standard framework to regulate their capability management practices (Lecluyse et al., 2018).

The final finding is about the relevance of dynamic capability theory to research centres. Specifically, dynamic capability theory suggests a business model managing key decisions in sensing, seizing and transforming and how these decisions must be made to create competitive advantages under changing environment. This theory is relevant to industrial organisations who create and sustain their niche while adapting to the market landscape. In contrast, research centres in the HMVC are concerned with how to innovate and commercialise technologies which drive sector growth, enabling aneventual change to the market landscape. To do so, research centres need to manage capabilities in a way that is not specified by the dynamic capability theory.

As our review results indicate that capability management of research centres is not fully recognised, it is necessary to investigate this knowledge gap by capturing views from the research centres. Hence, key practitioners from the HVMC were interviewed to understand their centres' operating characteristics and capability management issues.

3. Interviews

3.1 Overview

All seven research centres of the HVMC were contacted but only six of them agreed to participate while another non-HVMC manufacturing research centre was also involved. In total 16 practitioners were interviewed on-site at their research centres. All the face-to-face interviews were recorded and transcribed, and each one lasted around an hour. All interview questions can be found in the appendix. Given the knowledge gap, only practitioners (as reported in Table 8) with technical background and decision making authority were interviewed.

"Table 8"

3.2 Interview findings

To echo our review findings, the interview was used to capture valuable information from the practitioners about capability definition (RT3) and the challenges (RT1). Table 9 and Table 10 summarises their perspectives over RT3 and RT1 respectively.

3.2.1 Definition of capability

"Table 9"

Capability is defined by practitioners as equipment and knowledge which reinforces the importance of both human capability and technology capabilities. Table 9 categorises research centres' capability in three dimensions, people, equipment and projects, which together form the basis of decision-making across the HVMC.

In addition, research centres are required to understand in which project / market their capabilities can meet the client needs. There could be some cases that the capabilities of research centre are deemed mature for one project / market, but immature for another, e.g. automotive vs aerospace. Therefore, it is important to acknowledge the fact that capability management could be project- or market-driven.

3.2.2 Challenges of manufacturing research centres

Table 10 presents a list of major challenges captured from practitioners. The challenges are ranked by their popularities, and are associated with capability , operations , or strategic management.

"Table 10"

The most popular group of challenges highlights the link between operations management and strategic management. This includes "*difficult to define strategy for the HVMC*", "*funding related challenges*", "*how important technology is to industry or company*", and "*lack of awareness of the market / destination*". This reinforces the fact that strategic and operational decisions are significantly correlated and there is no exception in research centres' environment.

The second most popular group of challenges suggests a strong link between capability , operations and strategic management. This includes "*the issue of aligning new technologies with business cases*", "*assumption-driven project planning*", "*understanding of project requirements*" and "*technology-specific training*". This group represents one of the main difficulties of overcoming the valley of death as capabilities associated with projects without a valid business case will not be strategically sustained.

It also dictates how research centres should manage their operations and resources to meet industrial needs.

The third most popular group of challenges describes operations management as a standalone issue. This includes "*different perspectives between Academia and Industry*", "*getting partners' inputs*", "*balancing between technology push and application pull*" and "*handover of technology*". This emphasises the importance of involvement from key supply chain partners in order to ensure a good balance between supply and demand for each specific technology capability.

The next group of challenges is relevant to capability management which can be described by "*lack of knowledge / skill s/ experience in bridging the valley of death*", "*balancing between effort and benefit from new technologies*", and "*taking long time to develop*". This calls for the importance of research centres' capability management approach which helps address important trade-offs when developing / improving / sustaining technology capabilities s. Last but not least, the link between capability management and strategic management is mostly recognised as "*the middle bit of TRL scale*" which is a key step of turning ideas/concepts into commercial application, i.e. the valley of death.

In this connection, research centres should understand and hence define their own capabilities. Practitioners explained that "*most of that (capability) justification happens when clients visit research centres and machines are shown to clients; that's a lot of credibility to a lot of things that we claim in terms of saying that we can do this in this amount of time*" (P7). Practitioners also discussed that capabilities could be described as "*methodologies*" (P11). The current process of managing capabilities is informal and inconsistent, hence it requires *"a leap of faith on their (clients) part*" (P8). It shows that research centres struggle to define their capabilities and this reinforces the fact that no existing tool is applicable to the research centres in the HVMC. This gives rise to the need of developing a new capability management tool.

Regarding the role of this new tool, most practitioners suggested that it would be more beneficial if the tool can serve as "*capability maturity framework*" (P1,P9,P10,P12,P13). For example, P10 described the need for capability framework as "*when you look at collaborations on an industrial projects or R&D, understanding where you sit as a centre – compared to other centres and what part you are bringing to the parties is very interesting and very useful.*" On the other hand, the majority of practitioners replied that the two concepts, technology and capability, cannot be separated as "*you couldn't do one without the other*" (P2,P3,P7,P8,P11,P14,P16). This suggests that capability should be defined and measured in relation to its maturity rather than its readiness which contradicts the current capability management literature (Tetlay & John, 2009). Next, practitioners were asked about obstacles specific to capability management approach of their research centres.

3.2.3 Operating characteristics of manufacturing research centres

Building on the obstacles specific to capability management approach of manufacturing research centres, their operating characteristics were defined as reported in Table 11. Each of these obstacles helps depict a specific operating characteristic which also presents an area for improvement towards bridging the valley of death. For example, "*load and capacity*" reveals the fact that research centres have been adopting capacity lag strategy to meet the industrial needs. Due to "*unclear definition of maturity*" and "*complexity and dynamism of the research environment*", they have been less proactive in planning ahead. "*Low awareness of capability*" and "*managerial issues*" also contribute to the lack of standardised capability management approach within the HVMC leading to silo effect. This highlights a revolution that the new framework could bring.

"Table 11"

3.3 Summary of interviews

Interviews highlight that capability and technology are two key concerns linking to capability management issues within the HVMC. In addition, it is advised that a new capability management framework should help all research centres understand what capability should be improved / developed, and how. P10 explained further as "*we looked at this across the HVMC and wanted to answer the question – what is our capability. Because fundamentally you want to be able to say we are here – point on the map – we want to go to there – other point on the map. The wide space we have got is between here and there, and we are going to do it by this route.*" Therefore, such a new framework will help assess the current capability of research centres and provide recommendations to enhance their capabilities.

4. Discussion

The paper aims to investigate the knowledge gap related to capability management of research centres. The main findings from both literature and interviews are summarised in Table 12.

"Table 12"

It is clear that the literature does not standardise the definition of research centres, hence, their operating characteristics as well as operating practice are not well-understood. This study is the first to identify research centres' unique operating characteristics through interviews and this uncovers major reasons why they struggle to manage their own capabilities. It is evident that maturity definition is not standardised in the literature and most of the existing maturity models are based on TRL/MRL approaches which do not illustrate "*processes*" required to achieve the level desired by research centres. Therefore, due to the lack of methodological framework, research centres find it challenging to align their capabilities with industrial needs for bridging the valley of death. Without such a framework, capability management practices are not regulated leading to diverse understanding and low awareness of capability management within the HVMC as confirmed by the interview findings. No standardised approach is found to differentiate and benchmark among different research centres. Thus, it is very challenging for the HVMC to decide what capabilities must be improved / developed to support its strategic growth. Without fully recognising their own strengths and weaknesses, research centres may undertake projects that are not compatible with their own capabilities, or do not create any strategic value to both themselves and the sector. This causes research centres to fragment and develops the silo effect.

A framework that can assess capability in relation to maturity rather than readiness and provide guidance to escalate centres' capability is appreciated by most practitioners. Surprisingly, although dynamic capability is a well-known capability management theory, it is not well-received by research centres, perhaps, due to their unique operating characteristics which are different from the industrial ones.

5. Managerial implications

There is a lack of standardisation regarding capability management within research centre environment due to challenges highlighted in Table 12, some opportunities are uncovered building on our interview findings (Table 9-11). One resolution is to define capability management which will help standardise managerial practices. Table 13 presents three key dimensions of capability management in which each dimension can be measured, hence, managed.

"Table 13"

5.1 People dimension

The human aspect has been widely highlighted in various management areas. Particularly, **empirical knowledge** is emphasised as one key feature of human capability (Alexander et al., 2020), (Cadorin et al., 2019), (Li et al., 2019), (Cukier & Kon, 2018). People are unique in learning as "*it is in these employees that firms not only find the greatest repertoires and diversity of knowledge but also the most flexibility in acquiring new knowledge"* (Liu et al, 2019). **Technical skills** are deemed to be another key feature (Alexander et al., 2020), (Leischnig & Geigenmuller, 2020), (Liu et al., 2019), (Cadorin et al., 2019). Being able to learn and improve, technically skilled personnel provide many organisations "*a basis for developing national competitiveness*" (Cacciolatti, et al., 2017) as well as "*cutting edge R&D services"* (Hauser, 2014), both are essential to overcome valley of death.

Literature also highlighted the importance of **soft skills**. As reported by (Cacciolatti, et al., 2017), such skills stem from "*personal attributes that enhance an individual's interactions as well as job performance and career prospects*". Employees need to *"be good communicators, ambitious and team players"* and motivate others to make independent yet prompt decision making. People with good soft skills have positive influence on the culture and structure of an organisation (Cadorin et al., 2019) and this also helps firms achieve exceptional outcomes (Ferreira et al., 2018), (Spring et al., 2017), (Saddozai et al. 2017).

5.2 Equipment dimension

(Toomey et al., 2019) highlighted that *"suitable environment, equipment and software are, of course, essential for any research project."* In a research centre environment, suitable would mean **unique equipment** (Spring et al., 2017), or "*a state-of-the-art equipment"* to help firms overcome valley of death (Hauser, 2010). Such equipment is vital to support the development of advanced manufacturing technology in enhancing firms' competitiveness, sustainability and social responsibility (Smina et al., 2019). Therefore, another concern is **the effectiveness of equipment** which is defined as the ability of equipment to enhance manufacturing process effectiveness and reduce cost (Esmaeel, et al. 2018).

However, equipment uniqueness / effectiveness alone does not guarantee successful outcomes and "*it should go hand in hand with human capability*" (Liu et al., 2019). This can be assessed by the **level of understanding of equipment** – employees' working knowledge towards the connectivity, specification and operations of the equipment (Toomey et al., 2019). Such understanding can not only prevent manufacturing losses, hence improve effectiveness (Becker et al, 2015), but also protect research projects from human-related disruptions (Braglia et al., 2009).

5.3 Project dimension

Maturity frameworks are imperative to achieve effectiveness and efficiency in project-oriented working environment (Silva et al, 2019) which is a key operating characteristic of research centres (Klessova et al., 2020), (HVMC website, 2020). In particular, the **collaborative nature** of projects has been stressed as foundation to project success (Tunca et al., 2019). Such collaboration would encourage teamwork between different stakeholders to create an **impact** on industry.

Another aspect is to make sure that project outcomes can meet project requirements, i.e. **deliverables**. While many project management tools are readily available to help project-oriented organisations (including research centres) fulfilling requirements (Silva et al., 2019), there is no panacea given the dynamism associated with the current state and final state of a project (Vrchota & Rehor, 2019). Therefore, research centres need to keep track of what has been delivered throughout the project lifecycle and learn from any deviations. It is, thus, essential to have the appropriate **project management skills** by including "*specialists from different areas and the coordination amongst different departments and companies"* (Silva et al., 2019). This also enables project managers to "*get acquainted with the latest developments from project management"* (Vrchota & Rehor, 2019) and manage the project triangle (time, cost and scope).

5.4 The novel capability management framework

According to (Liu et al., 2019), technology management is defined "*as the capability of a firm to reconfigure its technological capability to shape and accomplish its strategic and operational objectives."* However, research centres do not have the right framework to manage their technology capabilities s as confirmed by our literature and interview findings. Building on the three dimensions of capability management (Table 13), a novel framework is conceptualised.

This framework will address capability management in three dimensions, each with three sub-dimensions, hence total nine sub-dimensions. By aggregating measurements of all sub-dimensions, a maturity index will be developed for each technology capabilities. Similarly, by aggregating measurements of all technology capabilities s of a research centre, an overall maturity index will be also obtained for that centre. This framework will become a standard practice when assessing maturity gaps in each sub-dimension/dimension of technology capabilities s. A range of "*processes*" specific to each gap will then be devised to improve the maturity of technology capabilities s as well as research centres for bridging the valley of death. The framework will also help visualise research centres' maturity levels and demonstrate their capabilities in overcoming certain industrial challenges. Data collection will be key to ensure the comprehensiveness of all sub-dimension measurements and this will involve all parties within the same research centre. It is believed that, by knowing their own strengths and weaknesses, this framework will allow research centres to make better decisions over capability management, strategic management and operations management.

6. Conclusions

HVMC aims to advance manufacturing technologies and support UK's technological progression with by overcoming the valley of death. Hence, research centres should manage their capabilities through proper mechanisms that "*reflect the difference in the sectors and the maturity of the relevant centre*" (Hauser, 2014). However, our findings confirm that most of the existing capability management models are too complex and resource-intensive ((Machado et al., 2017), (Harter et al., 2000)), and not developed to support manufacturing research centres with unique operating characteristics . This reflects a lack of understanding towards capability management issues of research centres.

This paper is the first to investigate capability management of manufacturing research centres in the UK. Our literature review highlights *four* important issues: (i) a lack of standardised definition of research centres and their operating characteristics, (ii) a lack of standardised definition of maturity to direct capability, (iii) a lack of standardised procedure to define and manage capability, and (iv) dynamic capability theory is not specified from a research centre's perspective. These are then echoed with our interviews involving practitioners from research centres to highlight their major challenges and the need of developing a new capability management framework meeting their unique operating characteristics. Through interviews, challenges and opportunities towards capability management of research centres were identified to address the two main research questions, *RQ1: challenges of capability management* and *RQ2: how these challenges should be managed*.

This paper uncovers the need of a new capability management framework and provides its conceptualisation in the context of research centres. As a follow up, the framework will be developed to meet participants' expectations and validated across the HVMC and beyond.

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Appendix

Table A1: Interview questions

Section 1: Work Background	• Could you describe your research centre and its focus? • What are the strengths/competencies of this research centre? What are your responsibilities at this research centre? • Are your responsibilities directly or indirectly related to technology readiness or product development process?

Section 2: Valley of death	• Are you familiar with the concept of valley of death? • How would you describe the valley of death, to the best of your knowledge? • Should the valley of death (if it exists) be managed by a systematic approach? (*Strongly Agree/Agree/Neutral/ Disagree/Strongly Disagree*) and Why? • Why some technologies cannot have a successful transition between innovation and full commercialisation stage? • Could you give some relevant examples?
Section 3: Capability	• What is meant by capability of research centre? • What do you know about maturity of technology, and the process of maturing a technology depends on?
Section 4: Technology & capability development	• Do you use any process/tool that helps manage the technology development process? If answered '*Yes*' o Is it a software/methodology/policy that you use? o Why do you use this process/tool? o Was it commercially available? Or was it created especially for this research centre? o What is the outcome of that process/tool? o What is the process/tool measuring/what are the inputs? What benefits does it have? o Are there any shortcomings of this process/tool? If answered '*No*' o How do you manage product development process? o Why other industrial approaches have not been implemented at the research centre? o What if a research centre had a tool that could help manage the product development? • How do you convince the clients that the research centre can deliver certain projects? • Would it be more beneficial to have a tool that addresses technology maturity rather than capability maturity? • Why would the tool (*that you mentioned*) be more suitable/applicable? • In order to make the tool practical, what should be its main functionality? • If there was a tool that could manage technology development, what would be the best format of it? (*e.g. software/management methodology/policy*) and why? • Would it be possible to implement such tool within the HVMC? Why? • What would be the potential benefits/issues if a tool was applied within the HVMC? • What would be the reasons why such tool has not been developed already?
Section 5: Challenges of research centres	• What challenges modern research centre struggle with the most? • What challenges affect technology development the most? • What aspects/activities/tasks need immediate improvement? • Would a capability maturity tool be able to resolve these challenges and support immediate improvement?

Table 1: Key technology capabilities within the HVMC

#	Key Technology Capabilities	AFRC[1]	AMRC[2]	CPI[3]	MTC[4]	NCC[5]	NAMRC[6]	WMG[7]
1	Advanced Assembly	✓	✓	✓	✓	✓	✓	✓
2	Automation	✓	✓	✓	✓	✓	✓	✓
3	Design	✓	✓	✓	✓	✓	✓	✓

4	Digital Manufacturing	✓	✓	✓	✓	✓	✓	✓
5	Materials Characterisation	✓	✓	✓	✓	✓	✓	✓
6	Metrology	✓	✓	✓	✓	✓	✓	✓
7	Modelling and Simulation	✓	✓	✓	✓	✓	✓	✓
8	Netshape and Additive Manufacturing	✓	✓	✓	✓	✓	✓	✓
9	Resource Efficient and Sustainable Manufacturing	✓	✓	✓	✓	✓	✓	✓
10	Tooling and Fixtures	✓	✓	✓	✓	✓	✓	✓
11	Composites	✓	✓	✓	✓	✓		✓
12	Joining		✓	✓	✓	✓	✓	✓
13	Machining	✓	✓		✓	✓	✓	✓
14	Powder Technology	✓	✓	✓	✓		✓	✓
15	Visualisation and Virtual Reality	✓	✓		✓	✓	✓	✓
16	Electronics		✓	✓	✓			✓
17	Casting	✓	✓					✓
18	Formulation			✓				✓
19	Metal Forming and Forging	✓						✓
20	Power and Energy Storage			✓				✓
21	Printable Electronics			✓	✓			
22	Surface Engineering			✓			✓	
23	Biologics			✓				
24	Biotechnology			✓				
25	Flexible Manufacturing							✓
26	High Temperature Processing			✓				
27	Manufacturing with Polymers					✓		

[1]AFRC: Advanced Forming Research Centre, [2]AMRC: Advanced Manufacturing Research Centre, [3]CPI: Centre for Process Innovation, [4]MTC: Manufacturing Technology Centre, [5]NAMRC: Nuclear Advanced Manufacturing Research Centre, [6]NCC: National Composites Centre, [7]WMG: Warwick Manufacturing Group

Table 2: Research Theme 1 - Challenges

Sub-themes (ST)	Description	Examples
ST1a: What external factors affects company	External factors discussed: megatrends and market fluctuations, but also importance of performing so-called ‘horizon-scanning’ and its benefits to strategy development. Based on external factors, companies sometimes choose to modify their capabilities in order to develop same capabilities as their competitors.	(Lee & Kang, 2017), (Kalkan et al., 2014)
ST1b: Types of internal challenges	Types of internal challenges: understating of internal operations of an organisation, limited knowledge about company’s own capabilities, uncertainties in regards to new projects, lack of organisational learning capability, financial issues, time to market, willingness and motivation of employees, strategy execution etc.	(Boon-itt et al., 2017), (Srivastava & Gnyawali, 2010)
ST1c: Other challenges	Other challenges e.g. industry context, challenges related to SMEs and large firms were discussed in this ST.	(Druilhe & Garnsey, 2004)

Table 3: Research Theme 2 - Concept of Maturity

Sub-themes (ST)	Description	Examples
ST2a: Maturity of product/process/industry	The concept of maturity has no universal definition and often is subject-specific. Examples from literature describe maturity of products and processes; minority of papers mention maturity of industry; distinctions between existing industrial maturity scales were also discussed. Most relevant definition comes from (Ifran et al., 2019): “improvement of processes and structures which are monotonous by	(Ifran et al, 2019), (Druilhe & Garnsey, 2004), (Drejer & Riis, 1999)

	nature. So, maturity can be understood as the development in each domain of a specific profession or area of an organisation.”	
ST2b: Manufacturing sector and concept of maturity	For the manufacturing sector, the maturity of technology and processes is the most relevant concept. Only one paper discussed how concept of maturity affects manufacturing sector and what is needed to capture the idea of maturity.	(Machado, et al. 2017)
ST2c: Maturity models	Various maturity models are applied in different sectors, e.g. software development, supply chain, etc. There is also no standard maturity model even for each sector. The models most discussed were Capability Maturity Model (CMM), models based on CMM, such as People Capability Maturity Model (P-CMM), CMM integration framework (CMMi), or System Engineering CMM (SE-CMM).	(Silva, et al., 2019), (Huang et al., 2019)
ST2d: Other aspects of maturity	Aspects like importance of development of technology and its commercialisation were discussed in this ST.	(ElMaraghy, et al. 2012), (Tassey 2010)

Table 4: Research Theme 3 - Capability

Sub-themes (ST)	Description	Examples
ST3a: Development of capabilities	Before development of capabilities can take place, core capabilities have to be identified first. (Drejer & Riis, 1999) describes core capabilities as “those competencies that provide the firm with a competitive advantage via the execution of the competence … Core competencies have been built over time and are not easily imitated.”	(Heimeriks and Duysters 2007), (Koufteros et al., 2002)
ST3b: Types of capabilities	Types of capabilities in relation to two perspectives were mostly examined: 1) subject area (i.e. management or manufacturing) and 2) business context (i.e. services, product developers, manufacturers or universities). In addition, the concept of dynamic capabilities was also included in this ST. The definition and importance of dynamic capabilities in relation to industry and when creating competitive advantages was described by several authors.	(Ojha et al., 2020), (Fainshmidt et al., 2019)
ST3c: How capability affects performance	The topic of how development of capabilities and their continuous improvement affects customer satisfaction; which also highlights the importance of capabilities. Hence, “more fundamental aspects of firm performance (…) are rooted in competences and capabilities.” (Teece et al., 1997)	(Rosenzweig et al., 2003), (Brouthers & Hennart, 2007)
ST3d: Knowledge & information transfer	In order to develop capabilities, information needs to be transferred between the departments (within a company). By doing so, knowledge transfer grows and encourages data-sharing within an organisation. Hence, as the knowledge is distributed, the communication becomes clearer and barriers between the departments are removed. Thus, if the lessons learned are shared, the company becomes more effective and efficient.	(Kim, et al., 2012), (Newey & Zahra, 2009), (Heimeriks & Duysters, 2007)
ST3e: Technology transfer	Technology transfer and technology management are two important drivers towards competitive advantage of companies. Also some aspects related to uncertainties during technology transfer were mentioned.	(Lee et al., 2007), (Rosenzweig et al., 2003)
ST3f: Socio-technical systems	Socio-technical systems (i.e. employees and equipment) are considered as the most important assets of an organisation. Without human and technology capabilities organisations companies will not be able to perform at all. And so, neither innovation nor creative process would ever take place.	(Kalkan et al, 2014), (St John et al., 2001)
ST3g: Innovation	Various definitions of ‘innovations’ are proposed by different authors. Impact of innovation and how it helps firms stay on the market was also discussed. Authors mentioned that innovation is also considered “as an elixir for growth, profitability, and competitive advantage” (Pisano & Teece, 2007).	(Miyazaki & Islam, 2007), (Koufteros et al., 2002)
ST3h: Other aspects of capability	Other aspects of capability, e.g. resource based view, interaction between drivers and influence on capabilities, organisational capability were discussed. Resource based view describes impact of resources and capabilities on a company/firm. It also highlights the difference between tangible resources. “(e.g., financial assets, technology) or intangible (e.g., managerial skills, reputation)” (Montealegre 2002).	(Montealegre 2002), (Srivastava & Gnyawali, 2010), (Drejer & Riis, 1999)

Table 5: Research Theme 4 - Strategy

Sub-themes (ST)	Description	Examples
ST4a: Importance of strategy	“Without a strategic context, a company will not know on which data to focus, how to allocate analytic resources, or what it is trying to accomplish in a data-to-knowledge initiative … The more clear and detailed a firm’s business strategy, the	(Paiva et al., 2008), (Liu et al., 2005)

	more obvious what data and analytic capabilities it requires" (Davenport, et al. 2001).	
ST4b: Definition of strategy	It was recognised that every organisation has their own strategy which recognises mechanisms and actions that are repeated in certain manners in order to complete the vision of the organisation.	(Fuchs, et al. 2000)
ST4c: Manufacturing tasks & strategy	This ST discussed how manufacturing aspect fits into the overall strategy of an organisation and how that process is "a result of resources alignment, including information, knowledge and company's functions" (Paiva et al., 2008). "Manufacturing capability refers to the manufacturer's actual competitive strength relative to primary competitors, which should be aligned with the strategic goals of the organisation" (Chavez, et al. 2017).	(Chavez, et al. 2017), (Paiva et al., 2008).
ST4d: Impact of strategy on company	The impact of strategy on the company was frequently highlighted in the literature; also a strong connection between strategy and organisational performance was always found explicit. "Given the changing competitive structure of markets today, there can be no doubt about the value of understanding how managers can develop distinctive capabilities to support difficult-to-imitate strategic initiatives" (Montealegre 2002).	(Machado, et al. 2017), (Lee et al. 2007)
ST4e: Other aspects of strategy	For example: strategic planning factor, environment dynamism and strategy, cognition and strategy.	(Srivastava & Gnyawali, 2010)

Table 6: Research Theme 5 - Decision Making Process

Sub-themes (ST)	Description	Examples
ST5a: Importance of decision making	This ST discussed such aspects as: importance of decision making for strategy, or incorporating risk management into decision making process. It also mentioned how important risk management and risk assessment is before decisions are made.	(Rosenzweig et al., 2003)
ST5b: Attributes of decision makers	There are different elements to what makes a good decision maker (e.g. previous experience, ability to identify opportunities, communication skills, leadership skills etc.). But it is also important to show to employees how certain decisions are made, i.e. what were the elements of decision making process, what the decision making process looks like; or to simply involve lower level managers in decision making process in order to incorporate different points of view.	(Newey & Zahra, 2009), (Marsh & Stock, 2006)
ST5c: What influences decision making process	There are many factors that influence decision making process: organisational structure, culture and skills of employees, technology knowledge, customer expectations, financial aspects, etc. However, in order to make the decision making process simpler, literature mentions formal processes created to help managers understand why those particular process were put in place and help them make better decisions.	(Brouthers & Hennart, 2007), (St John et al., 2001)
ST5d: Other aspects of decision making	Other aspects of decision making, e.g. bias in strategic decision making, participatory decision making, tools for decision making and management, structural and infrastructural decisions.	(Drejer & Riis, 1999)

Table 7: Research Theme 6 - Academia & Industry

Sub-themes (ST)	Description	Examples
ST6a: Academic perspective	This mainly explains what is the motivation and role of universities. Moreover, "universities require the presence of effective internal mechanisms or frameworks to aid knowledge dissemination" (Alexander et al, 2020).	(Fischer, et al. 2017), (Alexander et al, 2020).
ST6b: Manufacturing companies' perspective	This examines the role and drivers of manufacturing companies, which is mainly driven by financial advantage and market position.	(Saemundsson & Candi, 2017), (Miyazaki & Islam, 2007)
ST6c: Importance of research centres/hubs	This discusses the importance of R&D hubs/departments which aim "to bridge the gap between the academic and industrial sectors of the R&D economy, but just how well they are achieving this is a subject of considerable debate" (Graff et al., 2002). Additionally they are "a driver of innovation in many industries and an important part of innovation and technology management" (Fini et al., 2019).	(Fini et al., 2019), (Guerrero et al., 2017)
ST6d: Other aspects of collaboration	This discusses collaboration between university and industry, and what challenges need to be considered when such collaboration is taking place, e.g. how many resources are needed, how much time each task will take and which management style should be applied, etc. Also, "technology transfer and knowledge commercialisation have become strategic priorities for many universities" (Leischnnig & Geigenmüller, 2020).	(Leischnnig & Geigenmüller, 2020), (Graff et al., 2002)

Table 8: Background of practitioners from seven research centres

Research Centre	Practitioner ID & Background	Major Responsibilities
Research Centre 1	P1 Engineering (Other)	Driving collaboration across the centre, connecting people through technology projects, and making sure that as a group (HVM Catapult) we offer more than we could individually.
Research Centre 2	P2 Mechanical/Automotive	Supervising bids and funding applications that help to progress technology road maps.
Research Centre 3 (not part of HVMC)	P3 Manufacturing	Driving international collaboration with both industry and research institutes. Also establishing some new funding opportunities for collaboration.
	P4 Metallurgy/Materials science	Managing the research program, but also business development, e.g. planning how to get our technologies out of fundamental research, scaled them up and into industry itself.
	P5 Metallurgy/Materials science	Responsible for improving a technology capability as a manufacturing option for companies in various industries.
	P6 Engineering (Other)	Responsible for most of the research development and process development i.e. fundamental research to technology development.
	P7 Engineering (Other)	Responsible for facilities, i.e. the whole building and the equipment.
Research Centre 4	P8 Manufacturing	To define, manage and deliver strategies, programmes and projects.
	P9 Mechanical/Automotive	Responsible for improving a technology capability as a manufacturing option for companies in various industries.
	P10 Engineering (Other)	Responsible for improving a technology capability as a manufacturing option for companies in various industries.
Research Centre 5	P11 Mechanical/Automotive	Driving collaboration across the centre, connecting people through technology projects, and making sure that as a group (HVM Catapult) we offer more than we could individually. Also looking at new technologies and seeing how we can help.
	P12 Mechanical/Automotive	Ensuring that the defined projects meet the desired outcomes from the academic and industrial perspective within the time frame and within the budget that's available.
Research Centre 6	P13 Mechanical/Automotive	Driving collaboration across the centre, connecting people through technology projects, and making sure that as a group (HVM Catapult) we offer more than we could individually. Also responsible for current members and their strategic contribution into the centre.
Research Centre 7	P14 Metallurgy/Materials science	Driving collaboration across the centre, connecting people through technology projects, and making sure that as a group (HVM Catapult) we offer more than we could individually.
	P15 Metallurgy/Materials science	Matching projects with technology readiness of both the materials and the integration of those materials into applications.
	P16 Metallurgy/Materials science	Ensuring that the defined projects meet the desired outcomes from the academic and industrial perspective within the time frame and within the budget that's available.

Table 9: Views of practitioners over capability definition

Dimensions	Answers	Practitioner
Equipment	*"Equipment/machines/available technology/scale up facilities/processes"*	1,2,3,4,5,6,7,8,10,12,13
People	*"Appropriate knowledge base"*	1,2,4,5,6,7,8,10,12,13
Projects	*"Capability to justify how the development process took place/scaling up"*	1,3,5,7,12,15,16
People/Projects	*"Right people applied to right projects"*	1,3,4,6,8,10,14
People	*"Combination of academic and industry people, which helps to have appropriate expertise in some areas"*	6,11,15,16
People	*"Ability to process new ideas/deliver new products/ability to adapt to new projects"*	5,8,11
Projects	*"Ability to deliver the expected outcomes within budget and on time"*	5,14
Projects	*"Capability to meet clients' requirements/(industry) demand"*	5,13
Decision making	*"Capability to make a decision which is the right market based on the resources you already have i.e. you will have high capability in one market but may have very low capability if you move to a new market with new requirements"*	1
Decision making	*"Capability as a wider view – it will drive the level of investment & rate of progress"*	13
Decision making	*"Providing body of evidence to show where the technology currently is and show that you are able to scale up– part of building trust – can you show that you will be a trusted partner?"*	4

Table 10: Views of practitioners over challenges of research centres

Categories	Answers	Practitioner
Operations management / Strategic management	*"Difficult to define strategy for the HVMC: setting strategic direction and allowing us to choose which technologies we should be investing our time and effort into and money. And allowing us to make conscious decisions around what we are not doing, which is just as important as what we should be doing/ We need to fill in gaps in our, at a strategic level, at an overall level/not fully developed strategy for technology/clarity in regards to strategy and capability development." "Each research centre should have a very clearly defined strategic plan of the technologies that they are investing and outputting"*	1,5,7,11,12,14
	"Funding related challenges: Funding applications; Different stages of product development require different funding; How the funding is managed i.e. where is the funding coming from?/Not having strategic partner that could invest in specific product development and push it further across the scale"	3,4,5,9,12
	"How important technology is to industry or company- are those technologies right for the company or a product is very tailored for one application – no room for broader picture"	7,12,15
	"Lack of awareness of application because you only consider one market/destination"	9,10
Capability management / Operations management / Strategic management	*"Sometimes research and business case are not aligned -finding the demand for technology/which capability should be developed/Connecting technologies with business cases/engagement with industry"*	3,4,6,7,9,10,11,12,13, 16
	"Many assumptions used when planning long term project"	13
	"Understanding requirements of the projects"	3
	"Training people to be able to use that technology"	9
Operations management	*"Different perspectives between academics and industry people: academics will have different interests and not always will be interested of developing product into the next stages/ bringing people together/ communication between scientists – technology developers, managers"*	3,5,6,7,10,11
	"Getting the partners to input into the process"	2,3
	"Not enough technology push/we get a lot of application pull"	9,10
	"The handover at the TRL levels/handover back to customers"	9
Capability management	*"Lack of knowledge/skills/experience in converting ideas into commercial reality/maintaining the skills base"*	2,3,11,13,14
	"The input and the intake of the new technologies"	8
	"Taking long time to develop – client may think it's too much time and it's not worth it-proving feasibility of a product"	3
Capability management / Strategic management	*"The middle bit of TRL scale (valley of death) i.e. not having technology capability to advance a product/technology development"*	3,4,5,7,9,13

Table 11: Operating characteristics of manufacturing research centres

Obstacles	Practitioner	Quotes	Operating Characteristics
Load and capacity	2	*"The main reason for not doing it is forming that link between what's required to prove progression of that framework and industry"*	Capacity is mostly developed to address the current load (need) not the future load, i.e. capacity lag strategy.
	4	*"Engineers prefer to work on developing a machine or an engineering project"*	
	5	*"Our biggest challenge is sort of keeping work coming through the door and delivering it and building the centre to be what it should be"*	
	6	*"We work with all the customers that we work with, and each one of those is pushing their own agenda to some extent"*	
Maturity of the centres	5	*"The centres aren't that mature"*	Maturity is not well-understood, hence is not associated with capability.
	8	*"It's probably just the age of the catapult. Too early for that"*	
	9	*"Maturity of the catapult"* *"The team working is still trying to be defined"*	
	14	*"In Catapult terms- it's quite relatively early."*	
	16	*"We will have capabilities in 15 or 20 different areas, but we wouldn't have the depth. So this also needs to be managed carefully"*	
Complexity and dynamism of the research environment	3	*"It was always seen as too big of a challenge."* *"It's too complicated to effectively it's always been too big an idea"*	Research need is highly uncertain and difficult to be forecasted. This discourages the use of proactive strategies.
	10	*"Simply because of the challenge of it … it's very dynamic."* *"The rate of change is so rapid. The challenge to understand what is going on and who is doing what etc"*	
	12	*"It's a very difficult task and to make it modular is very challenging."* *"To create a justification of capability is very difficult"*	
Lack of awareness	1	*"No one has thought to do it and no one has a framework to implement."* *"Lack of capability that goes together with strategic level."*	Capability of research centres is not well-understood, hence there is no standard tool to manage it
	8	*"I don't think it's being asked for by clients."*	
	11	*"Maybe lack of awareness of the need for it or benefit of it"*	
Boundaries between centres	11	*"I think partly also maybe due to again the boundaries and uncertainty about boundaries between different catapult centres"*	The silo effect is aggravated by low visibility of centres' capability and low awareness of centres' capability management.
Managerial issues	7	*"Without the central catapult pushing it, it's hard to get all the centres to come out and say, yes let's all work together and do it"* *"Having standardised practices and common understanding across the catapults"*	

Table 12: Major findings identified from literature review and interviews

Literature findings	Interview findings
Lack of standardised definition of what research centre is and what it does. The operating characteristics of research centres are not clearly defined. Hence, their role is vague and this impacts their operating practice.	Unique OCs of research centres are identified as: capacity development is led by needs, maturity is not well-understood and not associated with capability, uncertain needs discourage the use of proactive strategies, no standard capability management method is adopted, and the silo effect is aggravated due to low visibility of centres' capability and low awareness of centres' capability management.

Lack of standardised definition of maturity which is essential to direct capability development. Existing TRL/MRL approaches only assess "what has been achieved" but do not illustrate "how it has been achieved". Existing maturity models are not specific to research centres and it makes maturity measurement a big challenge.	• The biggest challenge for research centres is to align new technologies with business cases. Hence, a new methodological framework is urged to define and measure capability in relation to maturity rather than readiness. • The new framework is expected to not only assess maturity level as compared to others, but also illustrate "processes" required to achieve the desired level. • Two main benefits of the new framework are standardisation of capability management practices and unification of terminology while four potential issues are identified as integrability, user engagement, accessibility and IP protection.
Lack of standardised procedure to define and measure capability. Most of the existing capability management frameworks/models are not specific to research centres whose capability management practices need to be regulated.	Capability of research centres is mostly defined as equipment and knowledge. However, there is a lack of common understanding towards capability management across research centres.
Dynamic capabilities theory is mainly discussed from an industrial viewpoint and it overlooks both the operating environment and operating practice of research centres.	Dynamic capabilities theory is not well-received by research centres.

Table 13: Dimensions of capability management

Dimensions	Sub-dimensions	Descriptions	References
People	Empirical knowledge	Embodied by creative, bright and skilled employees who have expertise in their roles.	(Alexander et al., 2020), (Li et al., 2019), (Cukier & Kon, 2018)
	Technical skills	Technological knowledge and skills that provide cutting-edge R&D services to industry/business.	(Leischnig & Geigenmuller, 2020), (Liu et al., 2019), (Cadorin et al., 2019)
	Soft skills	Personal attributes that enhance an individual's interactions as well as job performance and career prospects.	(Ferreira et al., 2018), (Spring et al., 2017), (Saddozai et al. 2017)
Equipment	Uniqueness	A state-of-the-art equipment to help firms with a range of activities from proof-of concept to production validation.	(Toomey et al., 2019), (Sminia et al., 2019), (Hauser, 2010)
	Effectiveness	Enhanced through increasing process effectiveness and reducing cost.	(Esmaeel, et al. 2018), (Noh et al., 2018)
	Level of understanding of the equipment	Employees' working knowledge towards the connectivity, specifications and operations of equipment.	(Hitt et al., 2016), (Becker et al, 2015), (Braglia et al., 2009)
Projects	Impact and collaboration	Stronger collaboration enables lower risks and higher impact upon project completion.	(Tunca et al., 2019), (Vrchota & Rehor, 2019)
	Deliverables	Monitor progress and generate outcomes to meet project requirements.	(Silva et al., 2019), (Vrchota & Rehor, 2019)
	Project management skills	Coordination of various activities, expertise, and resources to manage the project triangle.	(Silva et al., 2019), (Jabbouri et al., 2019)