An exploration of critical risk factors in manufacturing projects

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Abstract

The aim of this paper is to examine, categorize and prioritize the critical risk factors that influence manufacturing-oriented projects. Utilizing data obtained from the metallic production industry in United Arab Emirates, we employ multi-criteria decision analysis encompassing the '*Best-Worst Method*' (BWM) for factor ranking and categorization. The outcome of this exercise being the development of substantial proficiency in risk management that will have a significant impact on the overall success of projects commissioned within the manufacturing space. Findings drawn against an integrated '*Technology–Organization–Environment*' and '*Four levels of uncertainty*' framework suggests that '*Automation*', '*Cycle time*', and '*Feed rate*' (technological factors), '*Manpower utilization*' and '*Agility*' (organizational factors), and '*Occupational health and safety*' (environmental factors), ranked highest in terms of critical risk factors likely to impact upon the outcome of manufacturing projects.

Originality/value: This paper makes a specific contribution to the literature in that our use of an integrated '*Technology–Organization–Environment*' - '*Four levels of uncertainty*' framework as a risk intelligence focused typology allows us to focus on *proactive* as against *reactive* management of risk. This forms the core element of our theorization of risk knowledge as risk intelligence.

Keywords: Projects; Risk intelligence; Manufacturing; Success factors; 'Best-Worst Method' (BWM); '*Levels of uncertainty*'

1. Introduction

1.1 The context

What is of interest us in this study is the consequences of risks on the successful delivery of projects commissioned and undertaken within the manufacturing space. While the need to examine, categorize and prioritize risk factors has in recent years drawn the attention of a number of scholars (see for example, Klober-Koch et al. 2018; Lazov 2019), our study differs from these studies in that we are particularly interested in contributing to the extant literature focused on developing a more mature approach to risk management that focuses on the *proactive* as against *reactive* prevention and detection against specific technological, organisational and environmental risks. Essentially, this implies an intelligence focused typology of risk.

Manufacturing represents an organized method of transforming raw materials and increasingly, services, into a final product using labour and/or machines (Kenton, 2020). The manufacturing sector is recognised to be undergoing major changes. These changes are being driven by a number of factors including increasing demands by customers for integrated products and services. In addition, the industry is experiencing the effect of rapid developments in data science, analytics and processing technology (Kusiak 2019). For example, the industry is experiencing significant changes due to the emergence of cloud computing which provides the competency to glean the capabilities of robust information technology systems without the need to operate highly expensive technology infrastructure. Furthermore, advancements in social media are providing manufacturers with the competencies to much more readily and easily undertake

information sharing. Manufacturing is also increasing focusing its attention on environmental factors (Lee et al. 2013).

1.2 Risks in manufacturing

The high level of interdependence between products (for example, some products are inputs for other products), and services (where products and services are integrated) creates significant risks in manufacturing processes, thereby making risk perverse in manufacturing projects. With the closer integration of products and services, manufacturing projects are likely to experience not only significant integration risks, but also significantly higher relational risks. For example, the closer integration of products and services creates highly interrelated and interdependent manufacturing systems where risks can have considerable unintended consequences rapidly propagating right across the entire manufacturing network; crossing from operations to other parts of the organisation. This scenario is likely to impose not only with significant recovery costs, but also major contractual liabilities on individual manufacturing firms.

To remain competitive, manufacturers are focusing their attention on a number of initiatives related to production cost reduction and enhancement of not only their processes, but also customer offerings. However, all these capabilities (which are disruptive), represent risk points for the manufacturing sector especially when processes are poorly monitored or controlled (Kumar et al. 2018; Hu et al. 2019). This is especially so for smaller manufacturing organisations. As both Patterson et al. (1999) and Lee et al. (2013) observe, because the manufacturing sector is generally dependent on public sector regulation (which appears particularly focused on larger manufacturers), and the reality that suppliers appear less oriented to drive manufacturers to develop robust risk management as part of their project management processes, manufacturing,

has had little incentive to focus their attention on risk and its management. Yet, how effective a small manufacturing organisation is at managing risk can have an impact on its capabilities and competency in relation to its ability to provide agreed products to customers.

There is therefore a major need for manufacturing organisations to gain a clear understanding of their risks and how these can be best managed (Lazov, 2019). Drawing from Marshall et al. (2019a), we go further to opined that what is actually required in manufacturing due to the reality that it is a sector highly susceptible to risk failures is an outlook to risk practice that is *proactive* in as much that it is able to "…*co-develop abstract and concrete risk forecasting knowledge*" (Marshall et al. 2019a; p. 645). An emergent approach to such *proactiveness* is the notion of '*risk intelligence*' (Tilman 2013).

1.3 Aim of the study

In light of the above, we set out in this study to examine, categorize and prioritize the critical risk factors that are likely to impact upon the successful delivery of manufacturing-oriented projects. In this light, we further an earlier case made by Marshall et al. (2019a) on the need to refocus the management of risk from '*risk management'* (which emphasizes reactiveness) to '*risk intelligence'* (which emphasizes proactiveness). To date, we are not aware of any studies that has either sought to provide a detailed examination, categorization and prioritization of critical risk factors in projects commissioned and undertaken within the manufacturing space.

2. Risk in manufacturing

2.1.1 What are risk?

A review of the extant literature suggests that there is no generally agreed definition of '*risk'* (see Marshall et al. 2018,2019a,2019b; Marshall and Ojiako 2010, 2013, 2015). One obviously relevant complication in any attempt to define risk is that we cannot ignore that risk is typically viewed as

encompassing both '*threats*' and '*opportunities*'. However, in decision making theory, reference to '*risk*' implies conditions where it is possible, but uncertain as to the likelihood of occurrence of an event deemed undesirable (Hansson 1996, 2004). Much earlier, Yates and Stone (1992), had suggested that risk consists of three distinct elements. The first relates to the potential of loses emanating from the risk. The second related to the implication of the specific loss while the third relates to uncertainty. In this context, '*Uncertainty*' will refer to "…*a state of not knowing whether a proposition is true or false*" (see Holton 2004; p. 21).

2.1.2 Types of manufacturing risks and their management

There are two general types of risks likely to be experienced in manufacturing (Su and Liu 2015; Kumar et al. 2018; Hu et al. 2019). *First*, risk can emerge from disruptions emanating from actions wholly outside the control of the manufacturing firm ('*Externally driven/strategic risk*'). These will include for example, natural disasters and major disruptions to supply chains. *Second*, risks can also emerge from 'everyday' operational challenges associated with internal process failures and the delivery and use of goods and services (Ulaga and Reinartz 2011). These *'Operational risks'* represents inherent vulnerabilities to the business operations of the individual manufacturer (Su and Liu 2015). As a result, operational risks is a key and central matter of concern to the impediment of manufacturing firms achieving high rates of performance. In this study, we are particularly interested in these second group of risks, in order words, '*Operational risks*'. Although encompassed by '*Externally driven/strategic risk*' (see Oliva and Kallenberg 2003; Stoughton and Votta 2003; Meier et al., 2010), '*Operational risks*' are more prevalent in manufacturing. Furthermore, despite being controllable by the internal processes of the organisation in question (Das and Lashkari 2015), they can have a considerable impact on for example, supply chains (Su

and Liu 2015). Operational risks will include technological and organizational risks as well as environmental-related risks.

Numerous studies have examined the management of manufacturing risks (see Lee et al. 2013; Deloitte 2015, 2016; Su and Liu 2015; Kumar et al. 2018; Lazov 2019; Zou et al. 2019). In addition, there are a number of studies that have focused their attention on either identifying specific manufacturing risks (Liu et al. 2007; Lee et al. 2013; Starling et al. 2020) or exploring the relationship between risk management and manufacturing performance (with mixed findings). For example, there are studies suggesting a positive relationship between the operation of well-articulated risk management processes and manufacturing performance (Hoffmann et al. 2013; Ellinger et al. 2015; Isoherranen et al. 2015; Li et al. 2015; Kumar et al. 2018). At the same time, other studies have found no such relationship (Kumar et al. 2018).

2.2 Risk intelligence

2.2.1 From risk management to risk intelligence

Despite considerable interest in the management of risk within the context of manufacturing (see for example, Lee et al. 2013; Su and Liu 2015; Lazov 2019; Zou et al. 2019), it will appear that current means of risk management are associated with a number of limitations which have prevented the effective and efficient creation and protection of value likely to be drawn from being able to identify and manage potential risks. An appreciation of the nature of such risk during the initial stages of manufacturing is likely to significantly enhance the process of '*Risk identification'* and '*Risk assessment'*, both which are critical to the notion of risk intelligence. For this reason, it is increasingly being accepted in the literature that organisations do need to go beyond traditionally articulated notions of risk management (Makridakis et al. 2019; Marshall et al. 2019b). Typically, the management of risk includes the process of '*identification'*, '*assessment'*, '*avoidance'*,

'*migration*' and '*monitoring*' (see Lee et al. 2013). Here, '*Risk identification*' will focus on identifying sources of sources of risk with a view to developing an appreciation of their inter-relatedness while '*Risk assessment*' focuses on evaluation of risks that are more than likely to potentially have an impact on the organisation (see Lee et al. 2013; Marshall et al. 2019a, 2019b; Singh et al. 2020; Al-Mazrouie et al. 2021). Competency in '*Risk identification*' does however require those who manage risk to possess an element of knowledge that will foster their ability to engage in some form of threat scanning (Marshall et al. 2019a). '*Risk avoidance*' focuses on the need to elude the likelihood that the risk will be manifested. Ultimately, both '*Risk identification*' and '*Risk assessment*' will be significantly impacted by '*Risk intelligence*' which we posit, goes beyond traditional forms of risk management.

'*Risk intelligence*' brings together three concepts, *risk* (Borch 1967; Holton 2004; Hansson 1989, 1999, 2004, 2005, 2010), *intelligence* (Kahn 2008; Breakspear 2013; Dover 2015) and *information (*Buckland 1991; Casagrande 1999; Floridi 2005; Vigo 2011*)*. A review of the literature suggests that both '*risk*' and '*intelligence*' have wide and strongly contested meanings while confusion may also arise in terms of how *intelligence* might be regarded as differing from *information*.

We had earlier defined '*risk*' as conditions where it is possible, but uncertain as to the likelihood of occurrence of an event deemed undesirable. Conversely, drawing from Humphreys (1979), we define '*intelligence*' as "*...the resultant of the process of acquiring, storing in memory, retrieving, combining, comparing, and using in new contexts information and conceptual skills*". '*Information*' which comes in three different forms, namely (i) the act of communication of knowledge (ii) the actual knowledge communicated and (iii) the actual nature of the value of such

information (see Buckland 1991), is construed as facts provided to reduce uncertainty (Casagrande 1999).

2.2.2 Risk intelligence of manufacturing risks, from information to knowledge

'*Risk intelligence*' in the context of manufacturing suggests an outlook to risk practice that is focused on *proactively* gaining a clear understanding of not only planned manufacturing output, but also anticipated product use (in effect, where it will be used and the condition of use). In effect, risk intelligence focuses our attention on the need for the management of risk to be *proactive* in dealing with risk. Organisations become *risk intelligent* by seeking, collecting, analysing and applying risk intelligence *information* within risk intelligence *processes*.

Risk intelligence *information* can be sourced from absolutely anywhere. This is to say, that for the manufacturing manager, risk intelligence can be sourced from right across the internal and external informational contexts of manufacturing. Some obvious sources include performance and other marketing data. The closer integration of products and services means that with marketing intelligence, the emphasis is on not only competitors, but predominantly on customers (Skyrme 1989; Rakthin et al. 2016). By already bearing the *intelligence* stamp, such informational sources may provide the foundation for the transition of *information* to *knowledge.* Most importantly, that information must be conveyed through appropriate organisational pathways (which are not necessarily formal), to where its *value* can be fully and quickly realised and exploited. In order to more fully understand the nature and scope of knowledge in risk intelligence, it can be helpful to consider the idea of *concrete and abstract risk knowledge.* As risk knowledge grows more complex and becomes more integrated within behavioural ways of coping among managers, prospects for verbal representation in the simplified language of manufacturing risk are likely to diminish. This

means manufacturing risk knowledge will increasingly be expressed in the form of abstract categories.

The extent to which we prefer to focus on concrete or abstract risk knowledge might usefully be considered as a question of which *mind style* we prioritise, perhaps as an acquired risk management habit, in order to learn about what is going on in the world. Gregorc's (1984) *mind styles model* calls attention to a *concrete-sequential* mind style, which has been a favourite for manufacturing managers for a long time, as illustrated by commonplace usage of sequential manufacturing methodologies. Drawing on this, it can be argued that manufacturing managers need a *concrete* mind-set focused carefully on the here-and-now of the *specific* conditions and challenges that confront them; just as importantly, they need a *sequential* mind-set which thinks *causally*, linking elements in a linear fashion, in order to think through the best ways to effectively and efficiently effect project phase transitions amidst completely unexpected risk and uncertainty. That is essentially what concrete-sequential mind styles are all about.
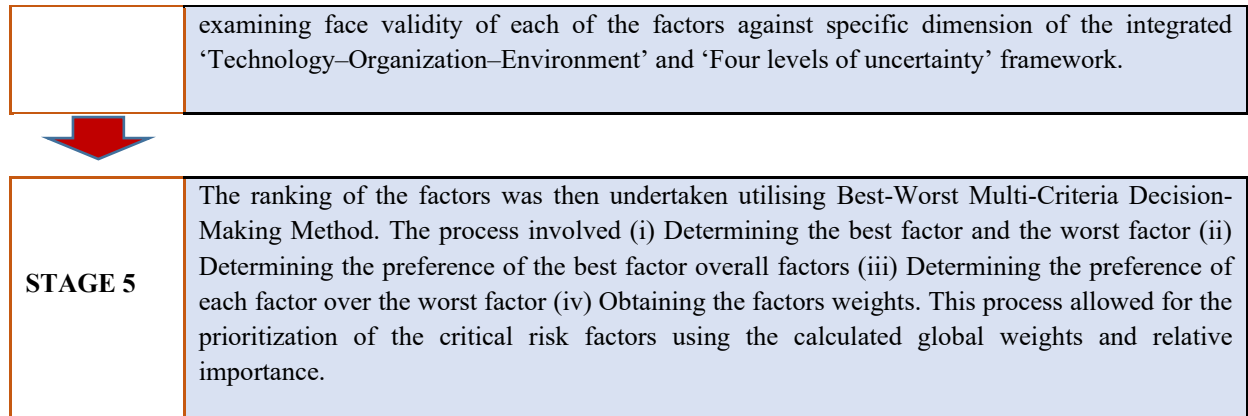
3. The study

We began the study by first identifying (through the literature) the critical risk factors that that we expect to represent a risk typology for manufacturing processing. Our approach is adapted from Chipulu et al. (2019) and Al-Mazrouie et al. (2021) and is diagrammatical represented in Figure 1.

The critical risk factors that influence production-oriented projects in the United Arab Emirates:
a 'best-worst method' (BWM) analysis

STAGES	Description
STAGE 1	To identify a risk intelligence-focused typology for manufacturing projects required the identification of critical manufacturing risk factors. This phase of the study involved undertaking a literature-based search of the risk factors. Drawing from Al-Mazrouie et al. (2021), these factors will represent abstract risk knowledge. Using specific keywords, we conducted a search of the academic literature using four research databases namely EDSCO, JSTOR, SCOPUS and Web of Science. The emergent literature was then organized into specific focused themes.
STAGE 2	Twenty-two risk factors were identified from the literature: (i) Digital fabrication (ii) Mechanical performance (iii) Formability (iv) Occupational safety and health (v) Cycle time (vi) Manpower utilization (vii) Robustness (Handling errors) (viii) Forecasting (ix) Resilience (x) Energy saving/efficiency (xi) Agility (xii) Product complexity (xiii) Integrability (xiv) Sheet metal thickness (xv) Automation (xvi) Reliability and maintenance (xvii) Feed rate and cutting speed (xviii) Equipment used (xix) Tooling design (xx) Dimensional precision (xxi) Improved communications between operations (xxii) Operations sequence.
STAGE 3	Refinement of the originally identified Twenty-two risk factors was undertaken utilizing a Delphi survey of ten professional managers working within the manufacturing sector in the United Arab Emirates (who were part time doctoral students). Two rounds of the Delphi survey resulted in the emergence of seventeen risk factors; (i) Digital fabrication (ii) Mechanical performance (iii) Formability (iv) Occupational safety and health (v) Cycle time (vi) Manpower utilization (vii) Resilience (viii) Energy saving/efficiency (ix) Agility (x) Product complexity (xi) Sheet metal thickness (xii) Automation (xiii) Reliability and maintenance (xiv) Feed rate and cutting speed (xv) Tooling design (xvi) Dimensional precision (xvii) Operations sequence.
STAGE 4	The categorization of the operations readiness factors involved classification of the 17 critical manufacturing risk factors via expert judgment. The approach that was adopted is similar as to that adopted by both Chipulu et al. (2019) and Al-Mazrouie et al. (2021) and primarily entailed

	examining face validity of each of the factors against specific dimension of the integrated 'Technology–Organization–Environment' and 'Four levels of uncertainty' framework.
STAGE 5	The ranking of the factors was then undertaken utilising Best-Worst Multi-Criteria Decision-Making Method. The process involved (i) Determining the best factor and the worst factor (ii) Determining the preference of the best factor overall factors (iii) Determining the preference of each factor over the worst factor (iv) Obtaining the factors weights. This process allowed for the prioritization of the critical risk factors using the calculated global weights and relative importance.

Figure 1. Diagrammatical representation of the research approach

3.1 The literature search

We commenced the study by first conducting a literature search on four research databases namely EDSCO, JSTOR, SCOPUS and Web of Science. For the search, we employed specific keyword search being '*Projects*', '*Risk*', '*Risk intelligence*', '*Manufacturing*', '*Manufacturing success factors*', '*Critical risk factors*', and '*Uncertainty*'. The next stage of the study involved the removal of publications which were deemed duplicates. This includes a number of instances where a paper had been published in a conference and later found also (an updated version), published in a peer reviewed journal. The remaining articles were then reviewed by the first, third and fourth authors leading to additional papers being removed that were deemed not necessarily focused on *Critical risk factors* in manufacturing. On completion of this process, further elimination of articles deemed not likely to contribute to a risk intelligence typology were eliminated (this time by the second, third and fifth authors). These remaining articles were finally ordered into themes more able to articulate a desirable risk-focused typology for manufacturing processes.

3.2 Identification of factors

On completion of the literature review, then then commenced with the factors. This stage of the process involved the comprehensive compilation of the measures factors from the identified literature which we opined explicitly serves as a typology for risk intelligence in manufacturing. From this process, we identified a total of 22 factors.

3.3 The Delphi survey

A survey was developed using a face-to-face elicitation to test the relevancy of the factors that were summarized from the literature. An overview of the expert panel is shown Table 1 (below).

Table 1: Experts Characteristics

Experts No.	Experts Code	Designations	Professional Background	Years of Experience
1	EX-01	Production/QC Engineer	Aeronautics Engineering	8
2	EX-02	Design Engineer	Mechanical Engineering.	13
3	EX-03	Production Engineer	Computer Science	5
4	EX-04	Supervisor/Site Coordinator	Mechanical Engineering.	12
5	EX-05	Supervisor	Industrial Engineering	32
6	EX-06	Supervisor	Industrial Engineering	11
7	EX-07	Designer	Computer Science	5
8	EX-08	Sales Engineer	Mechanical Engineering	5
9	EX-09	General Manager	Business Administration	6
10	EX-10	Site Coordinator	Mechanical Engineering.	7

To start with, the experts (all well-established practitioners in the field of manufacturing with over five years' professional experience and Engineering Management doctoral students at the University of Sharjah) were informed about the purpose of the survey and how their responses may affect the results. The survey consisted of the 22 factors along with their descriptions (shown in Table 2, below).

Table 2: The initial 22 factors along with their descriptions

S-NO	Factor/Criteria	Description
1	*Digital fabrication*	Combination of 3D modelling design of the product with 3D printing and machining with the use of new technologies.
2	*Mechanical performance*	This factor includes the tensile strength, modulus of elasticity, the yield strength, resistance tests performed. The management of these components and being able to handle the processes is the Mech. Perf.
3	*Formability*	Variable factor. Definition: The material going through plastic deformation without getting damaged.
4	*Occupational safety and health*	Risk factor. Ensuring the safety of the workers by providing them with the needed equipment(s) in terms of protection and safety.
5	*Cycle time*	A measure of the time needed for all the activities in a process to be completed (for our garbage chute, this includes bending, deforming operations, etc).
6	*Manpower utilization*	Factor of productivity. It helps in determining the worker's efficiency, and a measure of time utilized against the cost paid.
7	*Robustness (Handling errors)*	Trying to lower the chance of design changes by elimination. For example, distortion. Which is sudden change in design as result of temperature, etc.
8	*Forecasting*	The ability to predict future's client demand.
9	*Resilience*	Sustainable supply chain system. Assists firm with their risk management initiatives. Management being responsive upon any process or system deviations.
10	*Energy saving/efficiency*	Green firm.
11	*Agility*	Being qualified enough to respond to changes in the market rapidly and in a consistent manner.
12	*Product complexity*	A network of all the components in the product development process, and their relationships.

13	*Integrability*	The similarity between the computer software packages in the firm to ensure that web-planning system is doing well.
14	*Sheet metal thickness*	Gauge of the sheet metal, and a variable factor.
15	*Automation*	The use of the automated technologies in manufacturing processes, without any human interaction.
16	*Reliability and maintenance*	The focuses on the functionality of the product. Aiming to lower the chance of product' failure.
17	*Feed rate and cutting speed*	Rate at which drilling is performed. (Per min, per bit revolution)
18	*Equipment used*	Materials used throughout the production process.
19	*Tooling design*	A necessary factor before manufacturing; application and analysis of tools that will enhance the manufacturing overall productivity. For example, the die tool.
20	*Dimensional precision*	How close the dimensional precision is to the ideal product (customers' requirement or product provided).
21	*Improved communications between operations*	Relations between operations instantly; Following up.
22	*Operations sequence*	The order of the processes based on a specific product.

By considering expert elicitation techniques, which aims to reduce the bias in the responses; the experts had to choose if the factor is relevant to their processes or not using a '*YES*' or '*NO*' question. In general, "*likely*", "*possibly*", "*maybe*" were not included in the survey, and the research questions were not long. In addition, to categorize the factors and validate them, the experts had to relate the obtained factors to one (or more) of the three contexts: Technological, organizational or environmental context.

The relationship was assessed based on the experts' point of view according to their personal judgment that the factor falls in the associated context. The option of adding other factors that the experts might feel that it influences the manufacturing process has been considered, however, the experts decided that the factors that were obtained from the literature are enough and

demonstrate the major issues that influence their practices. Therefore, no additional factors were added to the set. The survey was undertaken in two rounds of questions (Round 01 and Round 02) that will be further discussed in the following subsections. For elicitation, the experts were told that the survey will be conducted anonymously; having them feel free to share their responses and personal judgements, without revealing their identity to other experts, which help in reducing biases that could result out of this.

In the first round of our Delphi study, all ten expert panel members participated in the survey and provided their feedback. However, three of the experts' responses showed that they were not convinced about the relevance of five factors namely; "*product robustness*", "*forecasting*", "*integrability*"; "*equipment(s) used*", and "*improved communications between operations*". For each of these factors, the expert panel members had assigned a "*NO*" to the specific factors. As a result of this, these five factors were removed from the survey. This left us with 17 factors for analysis (Table 3).

Table 3: The final 17 factors along with their descriptions

S-NO	Factor/Criteria	Description
1	*Digital fabrication*	Combination of 3D modelling design of the product with 3D printing and machining with the use of new technologies.
2	*Mechanical performance*	This factor includes the tensile strength, modulus of elasticity, the yield strength, resistance tests performed. The management of these components and being able to handle the processes is the Mech. Perf.
3	*Formability*	Variable factor. Definition: The material going through plastic deformation without getting damaged.
4	*Occupational safety and health*	Risk factor. Ensuring the safety of the workers by providing them with the needed equipment(s) in terms of protection and safety.
5	*Cycle time*	A measure of the time needed for all the activities in a process to be completed (for our garbage chute, this includes bending, deforming operations, etc).

6	*Manpower utilization*	Factor of productivity. It helps in determining the worker's efficiency, and a measure of time utilized against the cost paid.
7	*Resilience*	Sustainable supply chain system. Assists firm with their risk management initiatives. Management being responsive upon any process or system deviations.
8	*Energy saving/efficiency*	Green firm.
9	*Agility*	Being qualified enough to respond to changes in the market rapidly and in a consistent manner.
10	*Product complexity*	A network of all the components in the product development process, and their relationships.
11	*Sheet metal thickness*	Gauge of the sheet metal, and a variable factor.
12	*Automation*	The use of the automated technologies in manufacturing processes, without any human interaction.
13	*Reliability and maintenance*	The focuses on the functionality of the product. Aiming to lower the chance of product' failure.
14	*Feed rate and cutting speed*	Rate at which drilling is performed. (Per min, per bit revolution)
15	*Tooling design*	A necessary factor before manufacturing; application and analysis of tools that will enhance the manufacturing overall productivity. For example, the die tool.
16	*Dimensional precision*	How close the dimensional precision is to the ideal product (customers' requirement or product provided).
17	*Operations sequence*	The order of the processes based on a specific product.

3.4 Categorization of factors

The next stage of the process involved the authors developing and assigning dimension measures to each of these factors. The approach adopted (as in similar studies such as Chipulu et al., 2019 and Al-Mazrouie et al. 2021) involved the examination of face validity conducted by the authors. The value in the authors conducting this process is that they were more able to glean critical appreciation of the extant literature in order to provide a much more robust face validity assessment. In this case, five of the seven co-authors of this paper, all who have conducted and published research on the core element of this study and hereby are very conversant with scales

for assessing risk. At this stage of the study, each the expectation was that co-authors to participate in this process were required to show some indication as to which of the 17 critical manufacturing risk factors could be more appropriately aligned to a specific dimension of the integrated '*Technology–Organization–Environment*' - '*Four levels of uncertainty*' framework.

The '*Technology–Organization–Environment*' (TOE) framework is a scientific theory that is used to describe the influence of technology implementation. Firstly, it helps in describing challenges that any organization could face in implementing and adopting technology. Similarly, it helps in identifying organizational characteristics across all departments. Lastly, it describes environmental context of an organization considering all external activities. (Baker, 2011; Tornatzky and Fleischer 1990). The TOE framework does not only discuss the adoption of technological innovation, but also discusses any decision the company is in favour of implementing throughout its three contexts (Baker 2011) wherein our case, TOE framework is used to analyse the effect of the factors that were collected from the literature and through our survey.

According to Nilashi et al. (2016), technological factors mainly include external and internal technologies of an organization related to their process and equipment, which have innovation characteristics. This context describes the internal and external technologies that are relevant to the organization, both types of technologies including equipment and processes. For a manufacturing company, it is essential to consider the technological context before implementing any managerial decision. By the technological context, we define both the technologies that are being in use, and the ones that are still not brought to the firm (Baker 2011).

The organizational context is studied in accordance to what characteristics, incomes and resources are available, this includes the size of the firm, centralization degree, formalization

degree, and managerial structure, amount of "slack resources", human resources and relationships between employees (Baker 2011). The Environmental context refers to the construction of the business, location, who are the competitors, the macroeconomic background, and regulations pertaining to rules and regulation. In addition, as the '*Technology–Organization–Environment*' (TOE) framework analyses the factors that affect technological implementation, government regulations play a vital role when it comes to implementing new technologies and innovation (Baker 2011; Yeh and Yeh 2018).

The '*Four levels of uncertainty*' analytical framework was developed by Marshall et al. (2019a) as a means of categorizing and interpreting abstract (in order words, abstract theories of risk) and concrete knowledge of risks (which are fact laden). As shown in Figure 2 (below), the framework consists of four quadrants which serve to provide simple explanations of risk knowledge. The process we adopted (drawn from Chipulu et al. 2019), involved each of the authors explicitly stating the extent to which they opined that the 17 factors measures likely matched against the an integrated '*Technology–Organization–Environment*' and '*Four levels of uncertainty*' framework (shown in Figure 2).
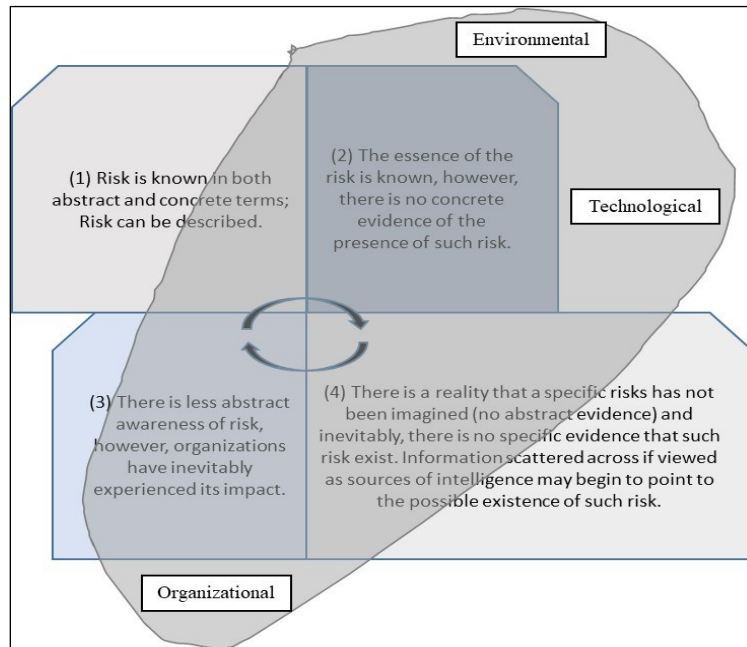
Figure 2. Integrated 'Technology–Organization–Environment' - 'Four levels of uncertainty' framework

If the response was 'not at all', then a value of '0' was assigned. Conversely, for 'to an extent matches this dimension', we assigned a value of '1'. Where it was deemed that the factors "matched a specific dimension", we assigned a value of '2'. Doing this allowed with the collation of the panel results, to not only reduce the number of factors as for each factor, we summated individual panel scores across the integrated framework.

For every measure, the total score through individual members of the panel for every dimension was calculated. Following this, individual measures of were then allocated. With no draws, we opined that the panel members were able to form a substantial agreement on what were deemed the most appropriate TOE dimension for each of the factors. This is shown in Table 4 (below).

Table 4: Categorizing of risk factors using TOE Framework

The technological context	
Factors	**Description**

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1	*Digital fabrication (T-1)*	The combination of 3D modelling and design with 3D printing, this factor requires the use of new manufacturing technologies, which will enhance the manufacturing processes, for example by using new design software and machines (Zaragoza et al, 2019).
2	*Mechanical performance (T-2)*	This factor is described as the overall efficiency of mechanical devices and how do they work compared to their ideal condition working state (Zaragoza et al, 2019).
3	*Formability (T-3)*	It is the process by mean the product undergo plastic deformation, without being damaged that is a challenging factor. This factor depends on the yield strength, the ductility of the material, and the strain-hardening rate (Zaragoza et al, 2019).
4	*Cycle time (T-4)*	It is a measure of the time needed for all the activities in a process to be completed. For any manufacturing process such as sheet metal, this includes the time for bending, deforming operations, etc. (Radin Umar et al, 2019).
5	*Sheet metal thickness (T-5)*	The sheet metal thickness is the distance through the sheet metal from the top to the bottom of the sheet. The experts at the company reported that this factor is so important when it comes to the production, as it directly controls the constraints that might be faced later in the production (Kumar and Hynes, 2019).
6	*Automation (T-6)*	Automation is the use of computerized machines during manufacturing processes, such as the CNC cutting machine which has the purpose of cutting the sheets into pieces during production; and has different types where the management of the company chooses the degree of automation that fit with the company's and processes' objectives (Kumar and Hynes, 2019).
7	*Reliability and maintenance (T-7)*	Reliability focuses on the functionality of the product, aiming to lower the chance of the product's failure while the maintenance focuses on overhauling and repairing the product. Increasing the reliability often reduces the need for maintenance; however, it should also be done on a scheduled time (Kumar and Hynes, 2019).
8	*Feed rate (T-8)*	This factor represents the speed the cutter that is usually measured units/minute (Kumar and Hynes, 2019). It was observed during our discussion with the experts, the number of jobs has the control over the feed rate of the machine. For example, if the jobs were five sheets on the CNC Punching Machine, the feed rate percentage would run between 40-45%. For larger number of jobs, higher feed rate is required to cope with the size of jobs.
9	*Dimensional precision (T-9)*	Dimensional precision is how close the measurements of the product produced to the ideal (customer requirement) (Umaras et al, 2011). As for our product (garbage chute in this study), unless the customer requested different dimensions the same dimensions will be used. For example, the elbow component and fire doors usually come with standard dimensions for safety issues.
	The Organizational context	
	Factors	**Description**

10	*Occupational health and safety (O-1)*	This factor is important from the point view of risk the employees of the organization are involved in. It affects the company's profitability as by management ensuring safety for the workers in workplace using the suitable equipment, prevention of additional costs is possible by reducing accidents and taking precautions against acts that cause illness (Yankson, 2012).
11	*Manpower utilization (O-2)*	This factor is associated with the employees and their productivity at work and it is simply a measure of the worker's performance against the cost incurred (the salary, benefits, etc.). The measure of this factor is important for the management in implementing managerial decisions when labour is involved, as it is a direct measure of effectiveness (Umaras et al, 2019).
12	*Resilience (O-3)*	It is the ability of keeping high quality manufacturing while trying to keep the cost low despite production variability and disturbances. This factor influences the manufacturing performance in a way that the management assigns the right workers do to the right job, this helps in preventing disturbances that might arise (for example rapid job changes: requires old experience workers) which helps in reducing operating costs keeping the aim of achieving high-quality products (Kumar and Hynes, 2019).
13	*Agility (O-4)*	This factor refers to the ability of managers (or people in charge) to deal with fast changes that happen in the market. This factor plays a role in keeping the company ahead of its competitors, achieve higher profits (Kumar and Hynes, 2019).
14	*Product complexity (O-5)*	This factor is simply a network of all the components in the product development process and their relationships. This factor is managed through the organizational structure, analysed and maintained through opinions of managers and experts on complex projects (Lindemann et al, 2009).
15	*Operations sequence (O-6)*	This factor can be defined as the order of the processes based on a specific product. In such an industry of sheet metal operations, every day the workers should have a list of ordered jobs to be performed in sequence. The list of jobs can contain part number, quantity to be produced, material used, etc. (Lindemann et al, 2009).
16	*Tooling Design (O-7)*	It is the engineering requirements the manufacturing organization needs to produce its products. This factor is related to human engineering, where in some places, engineers and experts develop tool concepts and apply them with the help of a software to develop different tooling designs that helps in manufacturing products (Umaras et al, 2011).
	The Environmental context	
	Factors	**Description**
17	*Energy saving (E-1)*	This factor refers to the usage of electricity, gas, or other forms of energy in an economical manner to conserve the environment. Energy saving and efficiency helps in the reduction of costs, going green, which helps in better utilization.

3.5 Ranking of risk factors using BWM

Best-Worst Multi-Criteria Decision-Making Method is a widely used multi-criteria decision making (MCDM) technique used for prioritizing and ranking factors in decision problems. BWM can analyse collected data in a structured manner with fewer input data than similar methods (Van de Kaa 2019). First introduced by Rezaei (2015), BWM has been applied by several authors in a variety of fields and sectors. Mi et al. (2019) provides a very detailed overview of the BWM method.

The BWM is characterized by its reference pairwise comparison, meaning that it requires less number of pairwise comparisons and less data points as compared to other multi-criteria decision-making techniques such as analytic hierarchy process (AHP). While BWM employs less number of comparisons, yet it maintains integrity of the decision problem that competes with other decision-making tools such as AHP (Rezaei 2016). A BWM survey can be undertaken using the pairwise comparisons. Six experts participated in the BWM survey and their responses are shown in Table 5 (six had participated in the original Delphi validation phase). The experts were informed before conducting the BWM survey about the purpose of the study and how their responses may affect the optimal weights for each factor.

The panel were asked to select the "*best*" and the "*worst*" factor in the Technological context and Organizational context as a starting point. For example, EX-03 selected "*Automation*" factor (T-6) as the best factor and "*Dimensional precision*" factor (T-1) as the worst factor in the Technological context. Later, the expert was requested to give preference of "*Automation*" over the other factors in the Technological context, and give the preference to all other factors in the Technological context over the "*Dimensional precision*" factor. The same applies to the Organizational context. To this end, it was possible to analyse the BWM survey results which are

presented in Table 5 – Best-to-Others of the Technological context while the rest of the results in

the appendix which serve as a direct input in the BWM.

Table 5: Best-to-Others of the Technological context

	BEST	(T-1)	(T-2)	(T-3)	(T-4)	(T-5)	(T-6)	(T-7)	(T-8)	(T-9)
EXPERT 1	(T-7)	6	4	7	5	3	2	1	2	9
EXPERT 2	(T-4)	9	2	4	1	3	2	4	3	2
EXPERT 3	(T-6)	8	3	4	1	2	1	4	2	2
EXPERT 4	(T-6)	8	3	4	1	2	1	4	2	2
EXPERT 5	(T-8)	6	4	7	2	3	1	3	1	4
EXPERT 6	(T-8)	8	5	4	2	5	1	2	1	3

The final weights were calculated using the BWM model with the help of excel solver as we

mentioned earlier in the methodology section based on the responses of the experts, the average

weights are considered as the final weights (presented in Table 6 - Technological context). The

weights obtained, are found in (Table 7). The average calculated consistency ratio (ξ) for the

Technological context is (0.065) and for the Organizational context is (0.140), both ratios are close

to zero, indicating reliability and accuracy of the results, after applying the step-by-step BWM

procedure.

Table 6: Factors weights within Technological context

Factors	Expert1	Expert2	Expert3	Expert4	Expert5	Expert6	AVG
(T-1)	0.055	0.022	0.020	0.031	0.049	0.034	0.035
(T-2)	0.083	0.141	0.080	0.083	0.074	0.055	0.086
(T-3)	0.047	0.070	0.060	0.023	0.020	0.069	0.048
(T-4)	0.066	0.220	0.180	0.172	0.148	0.138	0.154

(T-5)	0.120	0.094	0.130	0.125	0.099	0.056	0.104
(T-6)	0.166	0.141	0.240	0.250	0.208	0.230	0.206
(T-7)	0.276	0.070	0.060	0.062	0.098	0.138	0.118
(T-8)	0.166	0.094	0.120	0.125	0.228	0.183	0.153
(T-9)	0.027	0.141	0.120	0.125	0.074	0.092	0.096
(ξ)	0.055	0.063	0.060	0.078	0.087	0.047	0.065

The results show that in the Technological context, the Automation holds the highest value with an average weight of 0.206, followed by the Cycle time with an average weight of 0.154, Feed rate with an average weight of 0.153, Reliability and maintenance with an average weight of 0.118, Sheet metal thickness with an average weight of 0.100, Dimensional precision with an average weight of 0.096, Mechanical performance with an average weight of 0.086, Formability with an average weight of 0.048, and Digital fabrication with an average weight of 0.035.

Table 7: Factors weights within Organizational context

Factors	Expert1	Expert2	Expert3	Expert4	Expert5	Expert6	AVG
(O-1)	0.139	0.152	0.196	0.116	0.159	0.237	0.167
(O-2)	0.209	0.226	0.272	0.270	0.239	0.321	0.256
(O-3)	0.041	0.101	0.090	0.174	0.078	0.158	0.107
(O-4)	0.314	0.286	0.136	0.174	0.159	0.067	0.189
(O-5)	0.083	0.029	0.030	0.032	0.068	0.027	0.045
(O-6)	0.108	0.112	0.141	0.12	0.24	0.119	0.140
(O-7)	0.104	0.101	0.136	0.116	0.053	0.067	0.096
(ξ)	0.104	0.078	0.0758	0.077	0.402	0.154	0.140

The results show that in the Organizational context, the Manpower utilization holds the highest bulk with an average weight of 0.256, followed by the Agility with an average weight of 0.189, Occupational safety and health with an average weight of 0.167, Operation sequence with an average weight of 0.136, Resilience with an average weight of 0.107, Tooling design with an average weight of 0.096, Product complexity with an average weight of 0.045. While in the Environmental context there was only one factor based on the result of the Delphi survey, which is Energy saving, so BWM was not applied for the Environmental context.

4.   Findings

The results that emerges from the pairwise comparisons where the interrelations between the factors were constructed in both the technological and the organizational contexts. As for the *Technological context*, 15 pairwise comparisons were performed for the prioritization of the factors. For the *Organizational context*, 11 pairwise comparisons were performed to obtain the final weights as well as for the ranking. BWM survey results that based on pairwise comparisons by expert were served as an input. As for the third context, which is the *Environmental context*, the BWM was not applied. This is because it had only one factor in its context (*Energy saving (E-1)*), based on the survey results we obtained from the experts.

4.1 Technological Context

The results presented in Table 5 and Table 6, show that for the Technological context, the ranking of the factors is as follows: T-6>T-4>T-8>T-7>T-5>T-9>T-2>T-3>T-1. The Automation factor (T-6) falls in the first position exhibiting the highest rank in technological context with a weight of 0.206, followed by the Cycle time (T-4) in the second-highest position with a weight of 0.154, having a difference between automation (T-6) and cycle time (T-4) of 0.052. The ranking is in line

with the findings in literature, with automation being more significant than the cycle time. From previous studies, it is evident that the manufacturing companies tend to automate their processes in order to reduce the cycle time. Furthermore, in order for a manufacturing company to compete locally and globally, investments in advanced manufacturing technologies is a must as automation enhances the productivity in firms and improves the quality of the products by detecting production defects in earlier stages of production(http://www.advice-manufacturing.com/Automation-for-Small-cturers.html).After the cycle time, comes the third-highest ranked factor which is the feed rate (T-8) with a weight of 0.153, leaving a difference of 0.001 between Feed rate and cutting speed (T-8) and cycle time (T-4), which seems to be negligible showing that the cycle time and the feed rate factors are of equal importance in the manufacturing processes. Moving on, the reliability and maintenance factor (T-7) falls in the fourth place with a considerable weight of 0.118. This factor, in general is important to be considered in any manufacturing sector, the maintenance that is done for the machines on a regular basis has a reasonable cost when compared with the huge cost resulting from major breakdowns and corrective maintenance of the machine, which affects the whole production line (Krar 2015). These first four factors formed 63.1% of the total weight in the technological context.

The sheet metal thickness (T-5) is ranked number five in the list with a weight of 0.104, although it falls in the fifth position, however, this factor plays a vital role in the manufacturing process since it has a direct influence on the constraints that might be encountered later during the production; followed by dimensional precision (T-9) with a weight of 0.096, leaving the difference between T-5 and T-9 of 0.008, which is also an indication that those two factors influence the manufacturing process at considered case company equally, according to our study. Mechanical

performance (T-2) lies in the sixth position with a weight of 0.086, followed by formability (T-3) with a weight of 0.048, where the last factor in the list was the digital fabrication (T-1), having a weight of 0.035. Figure 4 below shows the prioritized factors within technological context.
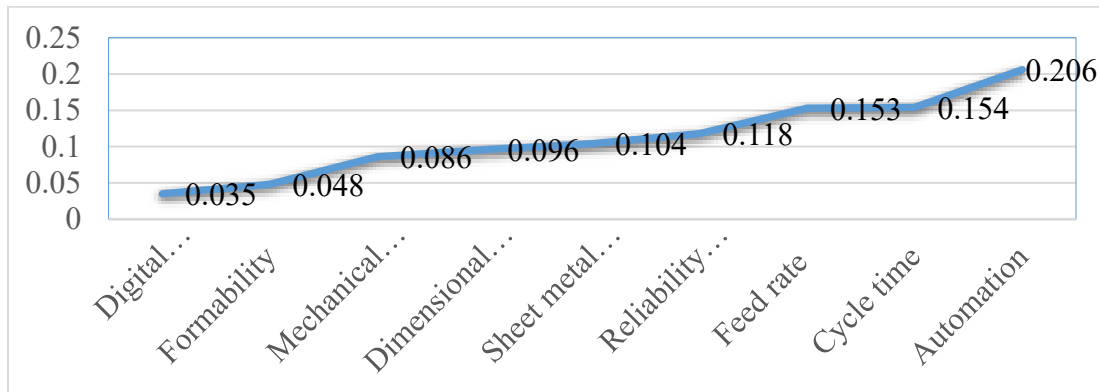
Figure 3: Prioritized factors within Technological context
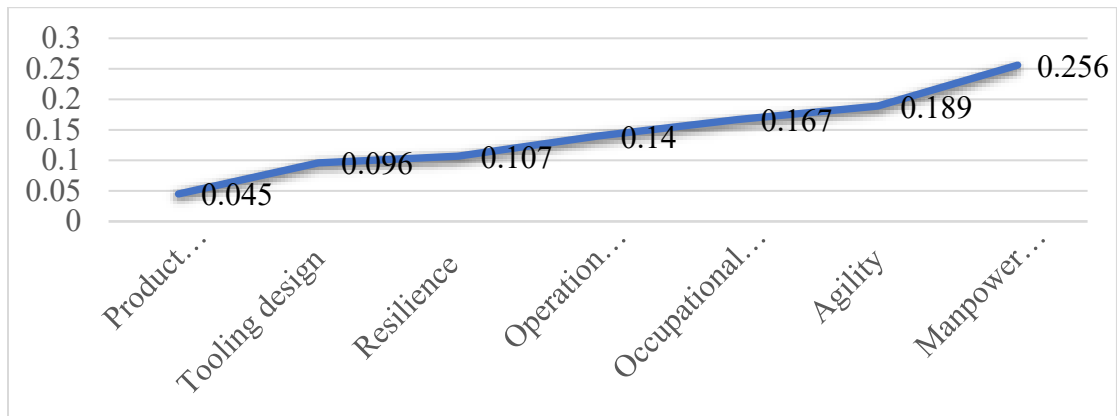
4.2 Organizational Context

For the organizational context, the results of the factors shown in Table 7 had the following ranking pattern: O-2>O-4>O-1>O-6>O-3>O-7>O-5. The manpower utilization factor (O-2) was the first in the list within the organizational context (O) by having a weight of 0.256. This result shows the importance of this factor, as focusing on the manpower utilization helps the management in achieving organizational goals faster and helps in cutting down costs. Moreover, the job will be clear to the worker, which will help in saving time and preventing errors that might occur due to vagueness of the tasks required to be performed (Kurata et al. 2015). The second highest factor in this context is Agility (O-4) with a weight of 0.189. As *X* metallic industry is conducting their business in an environment that is occupied by different competitors, they need to be agile to respond rapidly to changes that happen in the market. Also by being agile, the company will be able to carefully understand the business challenges, and turn the challenges into opportunities and

start working on them to sustain their position in the market (Zhang and Sharifi, 2000). Occupational safety and health (O-1) obtained a considerable weight of 0.167 and settled in the third position in the list. This factor plays a vital role in the organizational overall performance, as ensuring the safety of the workers means the workers are performing their tasks safely resulting in an increase in the company's productivity and profitability.

These first three factors formed 61.2% of the total weight of the (O) context. The fourth factor in the list is the Operations sequence (O-6) with a weight of 0.14. The job/operations sequence is generally prepared by the managers and experts involved in the manufacturing process. Supervisors usually have the detailed operations sequence including the job description, the time needed to finish the job, the tools that are going to be used and the deadline of the project. Paying attention to this factor is essential for the manufacturing firm to ensure that the production plan is moving in its right path. Although Resilience (O-3) was ranked fifth with a weight of 0.107, it plays a role in reducing the operating costs by maintaining the quality of the products that are being produced regardless of the variability and disturbances that might happen during the production and manufacturing processes. Tooling design (O-7) and product complexity (O-5) have 0.096 and 0.045 weights falling in   the sixths and seventh positions, respectively. Figure 4 below shows the prioritized factors within organizational context.

Figure 4: Prioritized factors within Organizational context

5. Conclusions

A valuable contribution of this study is the employment of multi-criteria decision analysis in the form of the '*Best-Worst Method*' (BWM) to examine, categorize and prioritize the critical risk factors that influence manufacturing-oriented projects. The outcome of the study which is framed upon an integrated '*Technology–Organization–Environment*' - '*Four levels of uncertainty*' risk intelligence typology finds that three technological factors, namely (i) '*Automation*', '*Cycle time*', and '*Feed rate*', two organizational factors, namely (i) '*Manpower utilization*' and (ii) '*Agility*', and one environmental factor, namely (i) '*Occupational health and safety*' are the most critical risk factors that will impact upon the success of manufacturing projects. As such, these six risk factors can be deemed a representative of a simplified, but yet, explicit account of manufacturing project risk.

The examination, categorization and prioritization of what are in effect critical manufacturing project risk is particularly relevant in that it provides managers with a platform to view these risk factors as 'risk intelligence factors'; in effect concrete, but proactive means to seek,

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collect, analyse and apply risk information on risk factors which are likely to be commonly engaged. Adopting this approach, we opine will serve to enhance the risk management competency ability of managers who are particularly concerned on the impact of delays to their projects. In particular, it allows managers to be able to draw upon what are in effect non-project specific, in effect, abstract risk 'known-unknown' knowledge of many prior failed projects in the manufacturing space, and transform this into project-specific, in effect concrete 'known-knowns' risk knowledge. Through this process, those responsible for managing the outcome of manufacturing projects are able to glean relevant knowledge that allows them through isomorphic learning (which enables transferable lessons between project situations), to know what they have previously not known about risks to their projects. Developing such knowledge in risk management is particularly critical for managers working in the United Arab Emirates where studies suggest that one in every two projects commissioned are likely to fail (Faridi and El-Sayegh 2006; Johnson and Babu 2020).

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