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Reducing uncertainty associated with managing technology innovation

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A R T I C L E I N F O

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A B S T R A C T

This research addresses the challenge of managing uncertainty associated with technology innovation, a process vital for economic growth and organisational sustainability. The study aims to offer novel insights on reducing uncertainty across the different stages of the innovation process by identifying interrelationships between technology innovation success factors. To achieve this, interpretive structural modelling (ISM) and MICMAC (a French acronym, which means "cross-impact matrix-multiplication applied to classification") were applied as research methodologies, and the directional relationships among success factors in the four stages (concept development, technology development, product development and implementation) of the technology innovation process were determined. Data were collected from a research and technology organisation that specialises in technology innovation. The evaluation revealed essential interconnections and rankings of factors within each innovation stage, and that the interrelationships between the factors vary across the different innovation stages. The original contribution of this study to innovation theory lies in demonstrating that the same success factors manifest differently across various innovation stages. This suggests the necessity of tailored management strategies for each stage, highlighting the need for a stage-specific approach in innovation management practices. Additionally, in terms of practical implications, this research aids managers by providing guidance on identifying the most influential factors and the varying order in which these factors should be prioritised for effective innovation management. The implications of this research extend to practical applications in the field of technology innovation by enabling a better understanding of the varying significance of success factors across different stages. Ultimately, this insight can assist in refining future policy frameworks and strategic planning in technology-oriented organisations. It is recommended that the ISM/MICMAC approach applied to determine the interrelationships and ranking between the success factors for each stage could be formalised into a technique for assessing technology innovation management to reduce uncertainty.

Michelle van Rooyen, Elma van der Lingen

1. Introduction

Technology innovation facilitates the growth and sustainability of economies and organisations (Cetindamar et al., 2010). However, the innovation process is characterised by uncertainty (Amoroso et al., 2017), which makes managing uncertainty a critical aspect of managing the innovation process (Gales & Mansour-Cole, 1995). Uncertainty, as defined by Jalonen (2012), arises from a lack of information, and can be reduced by systematically addressing critical assumptions about the consequences or characteristics of events and entities to gain information, as outlined by ISO (2020). A failure to manage the uncertainty associated with technology innovation can result in a loss of organisational resources – specifically, time and money (Samuelsson & Skoglund, 2020), as well as failed innovation attempts and possible financial and reputational damage to an organisation (Jalonen, 2012).

Despite a well-defined innovation process with identified success factors, managing technology innovation remains difficult (Cozijnsen et al., 2000), with only 5%–10% of innovation projects reaching commercialisation (Christensen & Raynor, 2013). When managing success factors for innovation, all factors cannot be addressed simultaneously; therefore, ranking of factors is required (Claessens et al., 2010). To determine the ranking order in which success factors should be addressed, one needs to understand how they are connected, which requires identifying their interrelationships. Determining interrelationships reduces the uncertainty associated with the order in which the factors should be managed. No research has been published where interrelationships were determined for factors in each stage of the innovation process. This research defines the innovation process as

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comprising four distinct stages, namely concept development, technology development, product development, and implementation.

In this study, the interrelationships between the success factors for each of the process stages are determined, aiming to reduce the uncertainty associated with how the factors are connected and their ranking order when managing each stage of the innovation process. Therefore, the objectives of this research are to:

1. Determine the interrelationships between success factors for each innovation process stage.
2. Contextualise how uncertainty associated with managing success factors has been reduced by determining interrelationships between the factors.
3. Evaluate if any differences exist between the way success factors are connected across the stages.
4. Provide recommendations to policy makers and managers for incorporating the implications of this research into innovation management strategies and practices.

The structure of the article is as follows: A theoretical background provides context for the characteristics of uncertainty in technology innovation. The methodology applied for this research is articulated, which includes a description of the techniques applied for data collection and analysis. The results of the study examine how uncertainty in managing each stage of the innovation process has been reduced. Finally, the article presents an interpretation of the results, along with overall conclusions and recommendations for future work.

2. Theoretical background

The concept of uncertainty, notably "Knightian uncertainty" as introduced by Knight in *Risk, uncertainty, and profit* (Knight, 1921), has been a pivotal distinction in the realms of risk and uncertainty (Dizikes, 2010). Knight argued that, in a constantly changing world, organisations must take advantage of new opportunities to innovate and generate profits despite having imperfect knowledge of future events (Dizikes, 2010). According to Knight, risk can be measured and applied to situations where the outcome is unknown but the probabilities can be calculated. In contrast, Knight believed that true uncertainty occurs when we cannot obtain all the necessary information to determine accurately the probabilities because of the uniqueness of the situation.

In the sphere of technology innovation, uncertainty plays a significant role, often intertwined with substantial investment where potential benefits are not guaranteed (Amoroso et al., 2017). Given the inherently uncertain nature of the future, it is expected that all innovation processes will contain an element of uncertainty (Jalonen, 2012). While experts such as futurists and analysts might attempt to predict future technological developments, their knowledge will always be incomplete (Nowotny, 2015).

The uncertainty associated with innovation has been widely studied. Three types of uncertainty are defined by Chalupnik et al. (2009):

- Aleatory uncertainty stems from the Latin word *aleator*, which means "dice thrower" (Merriam-Webster Dictionary, 2021). This uncertainty is irreducible and refers to the inherent unpredictability of processes. Aleatory uncertainty is usually quantifiable and aligns with the description of risk as measured uncertainty by Knight (1921). This type of uncertainty is manageable through proper risk management (Raz et al., 2002).
- Epistemic uncertainty, derived from the Greek term *episteme*, meaning "knowledge" (Merriam-Webster Dictionary, 2021), is a type of uncertainty that can be reduced and is in line with Knight's (1921) definition of true uncertainty caused by a lack of information. Increasing the available information can help to reduce this kind of uncertainty (Jalonen, 2012).
- Errors, a third type of uncertainty, stem from the Latin word *err*, which means to "wander from the correct answer" (Merriam-Webster Dictionary, 2021) Errors are sometimes viewed as a sub-class of epistemic uncertainty and occur owing to practical constraints. Errors are not associated with a lack of knowledge and could be addressed by reducing epistemic uncertainty, such as the introduction of proper innovation management protocols (Hengsberger, 2018).

Addressing each type of uncertainty in the innovation context involves specific strategies. Aleatory uncertainty, although irreducible, can be quantified and controlled through established risk management procedures that are applied globally (Project Management Institute, 2001). Errors can be reduced by introducing recognised technology- and innovation-management techniques (Cetindamar et al., 2010) and by ensuring that the innovation team possesses the relevant technical skills and expertise (Košturiak, 2010). Epistemic uncertainty is more difficult to address: no established standards or procedures exist to reduce this type of uncertainty because it tends to be context-specific. For this reason, this study evaluates how epistemic uncertainty could be addressed in the context of technology innovation, thereby contributing insights into the challenging nature of the process.

Publications have aimed to mitigate uncertainty associated with technology innovation by identifying success factors. These factors, varying by context, aim to alleviate persistent uncertainty related to technology innovation (Ensminger et al., 2004). Success factors for technology innovation are identified in numerous publications, such as Balachandra and Friar (1997) for new product innovation, Abetti (2000) for radical technology innovation, and Azarmi (2016) for technology innovation and commercialisation. Publications such as Tidd et al. (1997), Chiesa (2001), Verhaeghe and Kfir (2002), Cooper (2007), and Tidd and Bessant (2020) provide guidance about managing the factors that enable innovation success. These publications tend to evaluate the success factors for technology innovation from different perspectives relative to the process. The main viewpoints identified were input factors and throughput factors. Publications that identify success factors as inputs to the overall process include Rothwell (1974), Lester (1998), Balachandra and Friar (1997), Balbontin et al. (1999), Cozijnsen et al. (2000), Nellore and Balachandra (2001), Ismail et al. (2015), Kachouie and Sedighadeli (2015), and Azarmi (2016). Input factors are identified as a collection of factors that enable innovation success; however, the process itself is deemed a "black box" and the distinct process stages are not considered (Hao et al., 2017).

Although the identification of input factors reduces the uncertainty related to the aspects that facilitate technology innovation success, guidance is lacking about the ranking order in which these factors should be addressed. Reducing this uncertainty requires the determination of interrelationships to determine how the factors are connected, and the order in which the factors should be addressed.

Determining how the factors are connected reduces uncertainty about how the factors influence one another when managing the innovation process. For example, between any two factors – say, A and B – one of four distinct relationships might exist:

- A influences B: $A \rightarrow B$
- B influences A: $B \rightarrow A$
- A and B influence each other: $A \leftrightarrow B$
- A and B are unrelated: $A \neq B$

This means that, in the absence of identified interrelationships between the factors, an innovation manager faces the uncertainty of four relationships that might exist between any two factors. Determining the interrelationships between factors requires a pairwise comparison of all the factors that are being evaluated, which equals $\frac{n(n-1)}{2}$,[1] where n is the number of factors under evaluation. Since the relationship between a pair of factors might be any one of four options, the innovation manager faces the following predicament about how the factors are connected:

$$\textit{Number of options for relationships}^{\textit{Number of pairwise comparisons}} \quad (1)$$

$$4^{\frac{n(n-1)}{2}}$$

In the absence of information about how the factors are connected, four different interrelationships could exist between two factors, and 64 different options for three factors, while more than one million different options exist between five factors. If the relevant interrelationships between factors are not determined, there is considerable uncertainty about how the factors are connected when managing the innovation process.

Determining the interrelationships between factors further helps to reduce uncertainty about the ranking of the factors. When managing the process, it is not possible for all factors to be addressed simultaneously; therefore, information is needed about the order in which the factors should be addressed (Claessens et al., 2010). If this information is lacking, a factorial analysis helps to determine the number of different ways in which the factors could be ranked, and the following equation applies (Yong & Pearce, 2013):

$$f! = f * (f-1) * (f-2) * (f-3) * \ldots * 3 * 2 * 1 \quad (2)$$

$$= f * (f-1)!$$

If only two factors need to be managed – say, A and B – then the options for ranking the factors are two, namely A followed by B, or B followed by A. However, when three factors need to be managed, the factorial calculation becomes:

$$3! = 3*(3-1)*(3-2)$$

$$= 3*2*1$$

$$= 6$$

If three factors need to be managed, six ranking options are available, but the number of options increases significantly as the number of factors increases. For instance, with five factors, there are 120 ranking options, while seven factors have 5040 options, and ten factors have more than 3.6 million ranking options when information about the ranking of the factors is not available.

A way to reduce the uncertainty about how factors are connected and about the ranking of the factors when managing innovation is the identification of the interrelationships between the factors. Publications such as Romano (1990), Jensen and Harmsen (2001), Walter (2003), Jyoti et al. (2010), Wang et al. (2014), Mazdeh et al. (2015), Tarka (2018), and Sag et al. (2019) determine the interrelationships between the factors enabling innovation success. However, since these publications only evaluate a single process without considering the discreet process stages, limitations similar to input factors are associated with these studies. By evaluating the interrelationships between success factors for each of the distinct stages, this research makes a unique contribution to technology innovation management.

The success factors for technology innovation, as identified in a previous study (van Rooyen et al., 2020), were used in this study and summarised in Table 1. Table 1 includes the corresponding number that was assigned to each factor during the calculation steps when the interrelationships were determined and used in the Results and Discussion section.

3. Method

This study applied a qualitative research design with an exploratory stance towards gaining insights by focusing on non-numerical information, such as success factors (Saunders et al., 2016).

3.1. Research setting

This study determines the interrelationships between the success factors for each of the process stages in the context of a unit of analysis in an organisation. The selected organisation is a South African metallurgical research and technology organisation (RTO) with various technical and support departments. The RTO supports the expansion of the metallurgical industry through research, development, and technology transfer and innovation is core to its existence and sustainability for more than 50 years. In this study, four departments, that share the same technology innovation strategy and involvement in all four stages of the innovation process, were treated as a single entity.

3.2. Data collection

Ten experts from the selected group of departments were individually interviewed to gather data. The interviews took place over multiple rounds and aimed to achieve three objectives: first, to validate the relevance of the identified success factors within the RTO context; second, to determine the directional relationship between these success factors for each stage of the innovation process; and third, to confirm the accuracy of the results interpretation carried out by the authors.

The authors performed the calculations associated with the Interpretive Structural Modelling (ISM) technique, utilising the data obtained from the interviews. After confirming the individual ISM results with the ten experts, the findings were consolidated. A final focus group was then conducted with eight participants, involving one respondent from each department who participated in the initial interviews, as well as a department manager who had not taken part in the individual interviews. This approach allowed for verification of the results from a technical oversight perspective.

3.3. Data analysis

The identification of directional relationships between factors can be determined through techniques such as the analytical hierarchy process, the neural network process, interpretive structural modelling, and structural equation modelling. ISM and MICMAC (a French acronym for

Table 1
Success factors with corresponding numbers for calculating interrelationships, adapted from van Rooyen et al. (2020).

Factor number and name	
F1 – Technical skills and expertise	F2 – Entrepreneurial behaviour
F3 – Leadership skills and championing	F4 – Communication
F5 – Motivation	F6 - Creativity
F7 – Top management support	F8 – Organisational structures and processes
F9 – Organisational culture	F10 – Organisational strategy
F11 – Knowledge sharing	F12 – Teamwork
F13 – Open innovation	F14 – Supplier/service provider network
F15 – Partner/alliance network	F16 – Customer needs identification
F17 – Customer involvement	F18 – Market analysis

[1] For n factors, a pairwise comparison requires an n x n matrix – resulting in n^2 squares in a matrix. n squares on the main diagonal are not evaluated, and all other squares come in pairs. This results in the number of pairwise comparisons $= \frac{n(n-1)}{2}$.

"matrice d'impacts goises-multiplication appliqué an un classment", which means "cross-impact matrix-multiplication applied to classification") were selected for this study.

3.3.1. Interpretive structural modelling

ISM is a method that calculates the direct relationships between variables. The variables for this study are the group of success factors for technology innovation that were summarised in Table 1. An overview of the steps involved in the ISM process is shown in Fig. 1, followed by an explanation of each step.

This research began the process of interpretive structural modelling (step 1, Fig. 1) by identifying the success factors for technology innovation listed in Table 1. The contextual relationships between each success factor were established through interviews with technology innovation experts, and a pair-wise comparison of the factors was conducted (step 2, Fig. 1). The *i*th factor was compared individually with all the factors, from $(i+1)^{\text{th}}$ to the *n*th factor (Sushil, 2012). With $n = 18$ (Table 1) for this study, a total of $\frac{n(n-1)}{2} = \frac{18(18-1)}{2} = 153$ paired comparisons were made.

Using the paired-comparison results, a structural self-interaction matrix (SSIM) was developed (step 3, Fig. 1) that indicated the directional relationship between each factor. Four symbols are used in the SSIM to denote the direction of the relationship between factors i and j (where $i < j$) (Sushil, 2018):

- "V" denotes that factor i influences factor j ($i \rightarrow j$).
- "A" denotes that factor j influences factor i. ($j \rightarrow i$).
- "X" denotes that factors i and j influence each other ($i \leftrightarrow j$).
- "O" denotes that factors i and j are unrelated ($i \neq j$).

The fourth step of ISM is the conversion of the SSIM into a binary reachability matrix by substituting the symbols from SSIM with 1 and 0 according to the information provided in Table 2.

Using Table 2 as a reference, the reachability matrix is constructed such that, when the value of the (*i,j*) entry in the SSIM is V, the (*i,j*) entry in the reachability matrix is set to 1, while the (*j,i*) entry is set to 0.

The verification of the transitivity of the reachability matrix is necessary to uphold the fundamental principle of ISM, which states that if there is a relationship between factor A and factor B and another between factor B and factor C, then there must also be a relationship between factor A and factor C (Sushil, 2018).

Level partitioning (step 5, Fig. 1) uses the reachability matrix as a basis to obtain the reachability sets, antecedent sets, and intersection sets of factors. A reachability set comprises a factor and the other factors that it influences, indicated by the "1" values in the horizontal direction for each factor in the reachability matrix, while the antecedent set comprises a factor and the other factors that might influence it, indicated by the "1" values in the vertical direction for each factor (Dandage et al., 2018). By determining the intersection of these sets, the particular level of a factor in the ISM hierarchy is determined (Kumar Srivastava &

Table 2
Conversion of an SSIM into a reachability matrix.

SSIM	Reachability matrix	
	i,j	j,i
V	1	0
A	0	1
X	1	1
O	0	0

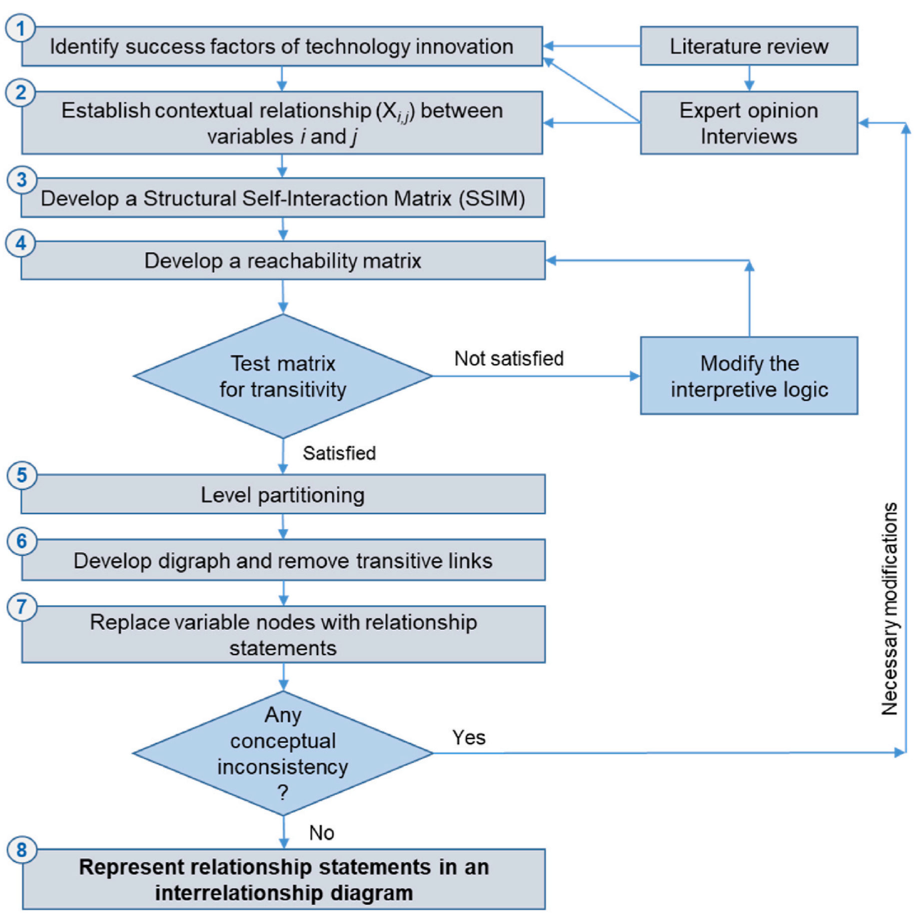

Fig. 1. Overview of interpretive structural modelling process, adapted from Dandage et al. (2018).

Sushil, 2014). Factors with the same reachability and intersection sets are considered first-level factors that only influence themselves (Wang et al., 2014). These factors are removed from the other factors, and the process is repeated to identify the subsequent levels until the final level is obtained (Rajan et al., 2020; Rizvi et al., 2019).

Steps 6 to 8 (Fig. 1) involve creating an interrelationship diagram in which the factors are depicted visually, based on the levels and connections established in the reachability matrix. The presence of a relationship between two factors – say, *i* and *j* – is represented by an arrow pointing from *i* to *j*. This diagram is also referred to as a digraph.

MICMAC.

ISM and MICMAC are often used together because they produce complementary results and have similar calculating processes (Guo et al., 2012). ISM focuses on identifying the direct relationships between factors, while MICMAC evaluates the indirect relationships among factors (Elmsalmi & Hachicha, 2013).

After creating the reachability matrix in step 4 (as seen in Fig. 1), the factors are categorised on the basis of their "driving power" and "dependence", using a four-quadrant matrix, as shown in Table 3.

The ISM and MICMAC evaluations were conducted for each of the innovation process stages (concept development, technology development, product development, and implementation), and the results are discussed next.

4. Results and Discussion

The sections that follow illustrate how the success factors (Table 1) are connected and ranked in each process stage. The application of ISM determines ranking, which means the order in which factors are addressed; and MICMAC assigns categories to the factors, enabling those in a particular group (Table 3) to be managed similarly. For instance, independent factors with high driving power and low dependence, identified through the relevant reachability matrix, are crucial drivers that require primary attention when managing the respective stages. For conciseness, this article only discusses the driving factors of each stage.

4.1. Concept development stage

The interrelationships between the success factors for the concept development stage are shown in Fig. 2. The concept development stage generally involves the identification of a problem, along with the recognition of a solution, need, opportunity, or new idea to solve the problem (Zirger & Hartley, 1994).

The RTO generally follows a market pull approach to technology innovation. When a market pull approach is followed, information and insights from a thorough *market analysis* usually form the basis for justifying innovation activities in the departments that were studied. In such instances, the market analysis drives the innovation initiatives, as shown in Fig. 2. The market experiences considerable volatility, and commodity prices can change drastically over a short period (Deloitte Insights, 2020); therefore, it is essential that the market analysis accurately identifies trends in the market to which the organisation should react rapidly. Common barriers to technology innovation are the lack of a clear market focus and insufficient market analysis performed by the organisation, resulting in the right customers and market segments not being reached (Bout et al., 2004). Further mistakes often made by organisations are that more focus is placed on technological aspects (technology push) and insufficient attention is paid to the market dynamics (market pull) (Cetindamar et al., 2009). The BlackBerry mobile phones were one of the great innovations in the market around the early-2000s (Hempel, 2010). At its peak, BlackBerry owned 20% of the global smartphone market; however, was soon overtaken in the early 2010s by touchscreen devices like the Apple iPhone (Allen et al., 2010). While Apple focused primarily on customer needs, the focus at BlackBerry was only on the product, and not the users (Trivedi, 2010). Despite being one of the first smartphones, BlackBerry failed to innovate and became complacent about how the market was changing (Moussi & van Amsterdam, 2017). In January 2022, BlackBerry stopped supporting its operating system on older models, essentially making the phones obsolete (Tung, 2022).

Table 3
MICMAC classification of factors, adapted from Jadhav et al. (2014).

Driving power	Strong	Independent Critical driving factors that require primary attention to ensure optimum results.	Linkage The instability of these factors can trigger a domino effect on other factors, which in turn can result in feedback loops.
	Weak	Autonomous Relatively disconnected factors. Only a few and weak links with other factors.	Dependent Automatic followers from other factors. Dependent and highly influenced by other factors.
		Weak **Dependence**	**Strong**

The market analysis enhances *knowledge sharing*, which is the second driving factor of the concept development stage. This means that, once a need or opportunity in the market has been identified, ideas, knowledge, and skills are shared among relevant team members to discuss various technical options. Knowledge sharing should extend across departmental boundaries to ensure that all relevant options are considered for the potential concept.

The *organisational strategy* is also a driver of the concept development stage; however, it is disconnected from the other two drivers, as reflected in Fig. 2. The organisational strategy is not influenced by any factors, whereas it does enhance many others. During the stage of concept development, insights from the market analysis guide the team to identify relevant technological opportunities or needs. While the strategy guides the departments about the long-term organisational plan for sustainability, it is not intended to restrict the analysis of the market, which could lead to unidentified and missed opportunities. The innovation team members analyse the market thoroughly to ensure that all possible needs or opportunities are identified. Once the need or opportunity is identified from the market analysis, the organisational strategy also does not influence the sharing of knowledge and ideas for considering potential technical solutions to the identified need. From the interrelationships between the driving factors for the concept development stage, a potential solution to an identified need is first explored thoroughly before the organisational strategy becomes influential.

Several successful and profitable organisations emphasise the importance of strategy for their innovation practices. An example is Tesla, which has a long-term goal of being the biggest car company in the world (Vance & Sanders, 2015). Conventional business logic is to create a "minimal viable product" of the first version of a product, which is usually sold at a reasonably low starting price (Furr & Dyer, 2020). Tesla, on the other hand, created the most luxurious, expensive, fully-featured sports car they could afford (Furr & Dyer, 2020). By following their strategy to create the most compelling car company of the 21st century by driving the world's transition to electric vehicles, Tesla dwarfs the competition as the most valuable car company in the world (FXSSI.com, 2021).

By identifying the factors that drive the concept development stage, as well as the way they influence each other, uncertainty has been reduced regarding how these factors should be managed. The results showed that the market analysis should be prioritised, after which it influences knowledge sharing. It was also shown that the organisational strategy is a driving factor, however, no interrelationship exists between it and the other two driving factors.

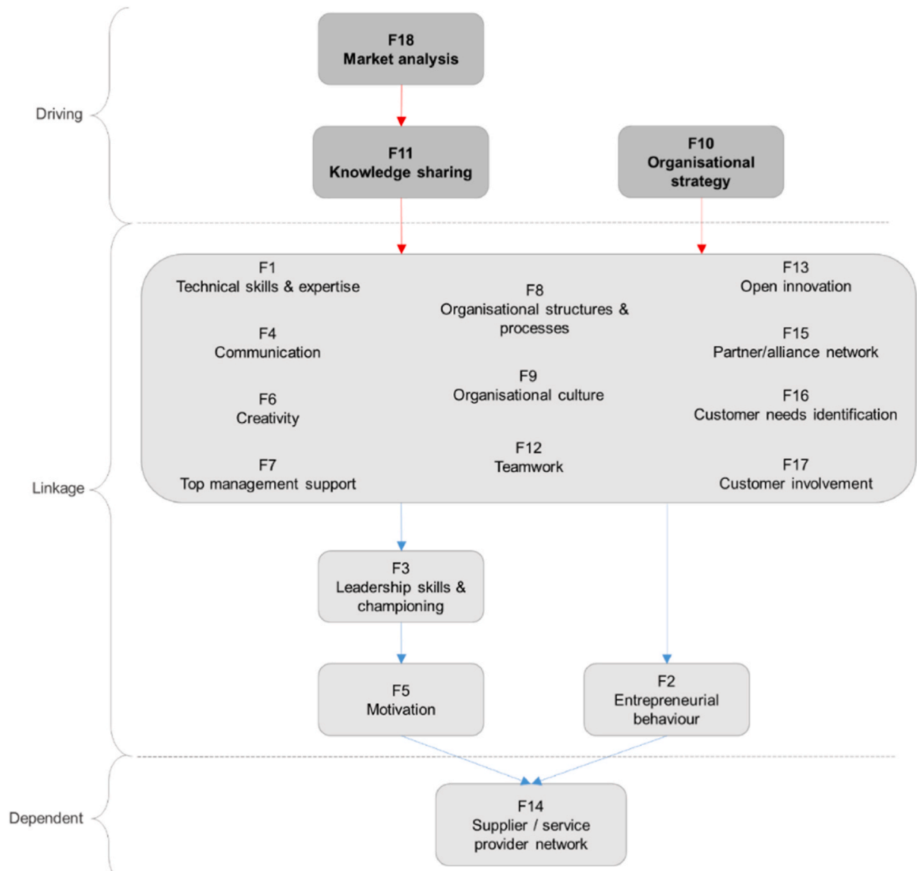

Fig. 2. Concept development stage: Interrelated success factors.

4.2. Technology development stage

The interrelationships between the success factors for the technology development stage are shown in Fig. 3. This stage involves detailed experimentation and the verification of the process parameters to define the design specifications of the technology (Cummings & Teng, 2003).

The technology development stage has more driving factors than the others, reflecting the concentration of involvement by the departments that were evaluated for this study. While concept development usually involves a small innovation team, the extent of the activities and interactions and the size of the innovation team generally increase during the stage of technology development.

As in the concept development stage, the *market analysis* is treated as a priority during the technology development stage. The purpose of the research and experimentation performed during technology development is to align the technical solution with the market need. The technology development stage involves the formulation of essential technical specifications that define the technology. If pertinent information from the market is misinterpreted, the innovation might not succeed in the marketplace. Therefore, verification between the technical development and the market need is important.

During the concept development stage, the innovation team might not yet have been formed; however, during the technology development stage, the team is established and possibly expanded to ensure that all the required disciplines participate. This requires effective *teamwork*. Teamwork is a driving factor – the first factor that is influenced by the market analysis (Fig. 3) and the first factor that is under the control of the organisation. The innovation team requires relevant and complementary skills to complete the technology development stage. However, to ensure effective teamwork, the members should get along and work together productively. This might require team-building efforts upfront to cultivate a sense of camaraderie. Building a team is generally not an easy task. The development of a team typically goes through distinct phases: forming, storming, norming, performing, and adjourning, as described by Tuckman (1965). Therefore, since teamwork is a driving factor, ideally the innovation team should be near the 'performing' stage of team development as early as possible during the technology development stage. Poor teamwork might jeopardise the success of the entire stage.

When effective teamwork is established in the innovation team, *knowledge sharing* is enhanced as members work together and guide each other through the technology development activities. Everyone in the team should be allowed to contribute and share their knowledge, which often requires mature conversations and respect for opinions and differences (Goleman, 1995). Knowledge and skills from all relevant disciplines should be incorporated into the technical scope. Even if effective teamwork exists among the members, the innovation activities might still be futile if knowledge is not shared adequately.

The alignment of the technology development activities with the market need and effective teamwork and knowledge sharing influences the *organisational culture*. Organisational culture is a complicated factor; you cannot see it, but you can feel its effect (Meyer, 2014). Since organisational culture is typically difficult to change (Denning, 2011), the preceding factors that directly influence this factor (Fig. 3) should receive particular attention. If an organisation's culture is not supportive of innovation, the effect on the rest of the innovation stage can be devastating (Walker & Soule, 2017). This means that, if it so happens that the culture of the departments needs to be changed, the focus should be placed on those factors in Fig. 3 that have a driving influence on the culture. If organisational culture is typically so difficult to change, could this be a reason for a failed innovation, even when all the other factors are in place (Connell et al., 2001)?

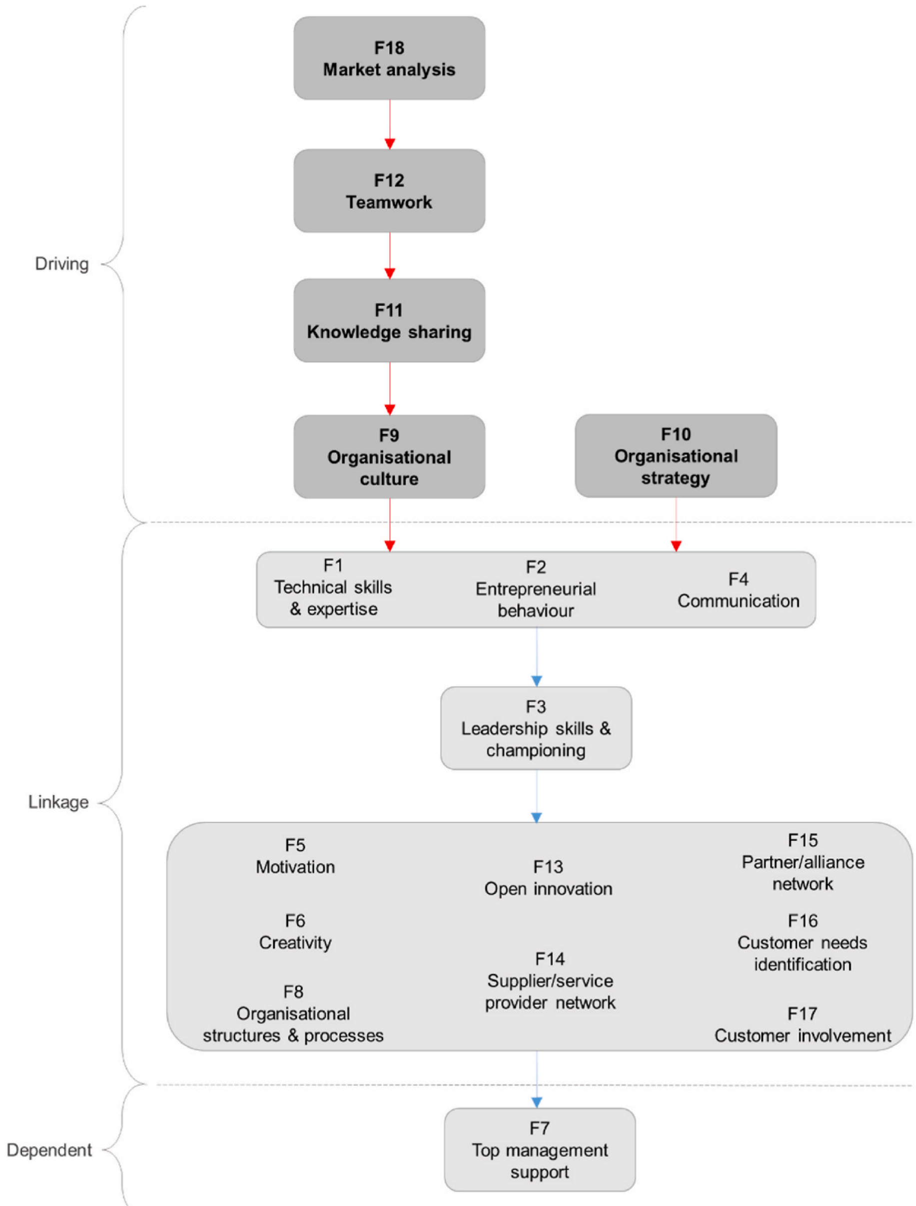

Fig. 3. Technology development stage: Interrelated success factors.

As was seen in the concept development stage, the *organisational strategy* is a driving factor; however, it is not influenced by other factors. The strategy is an external-facing, long-term plan for how the organisation will create and offer value to its customers and ensure sustainability (Malek et al., 2014). In the organisation, the strategy is based on a horizon that spans five to ten years. As such, the organisational strategy plays a crucial and consistent role that cannot be significantly impacted by abrupt shifts in the external environment. While it is important to recognise market needs or opportunities, the organisational strategy sets the parameters within which a solution should be formulated. As shown in Fig. 3, the analysis of the market and the organisational strategy do not influence each other during the technology development. Nevertheless, both factors provide direction to the departments regarding the scope of the innovation.

Determining the interrelationships that exist between the success factors reduced uncertainty regarding how the factors are connected and the ranking order in which they should be addressed. In the absence of this information, an innovation might have decided to prioritise creativity or communication when managing the technology development stage. However, these factors are not driving factors, therefore, if focus were to be placed on managing their influence on the other factors would have been limited. If, for example, top management support was prioritised as the factor to receive primary attention during technology development, it is doubtful that any of the other factors would have been effectively managed since top management support is the least influential factor in this stage.

4.3. Product development stage

Fig. 4 illustrates the interconnections among the success factors for the product development stage. This stage encompasses the determination of the product's functional requirements (Berkhout et al., 2006), and the identification of critical product attributes (Iamratanakul et al., 2008; Van der Heiden et al., 2016).

During the product development stage, many different engineering disciplines are involved in the innovation team, ensuring that every user requirement is satisfied and that the engineering design is performed accurately. Depending on the technology, the innovation team might

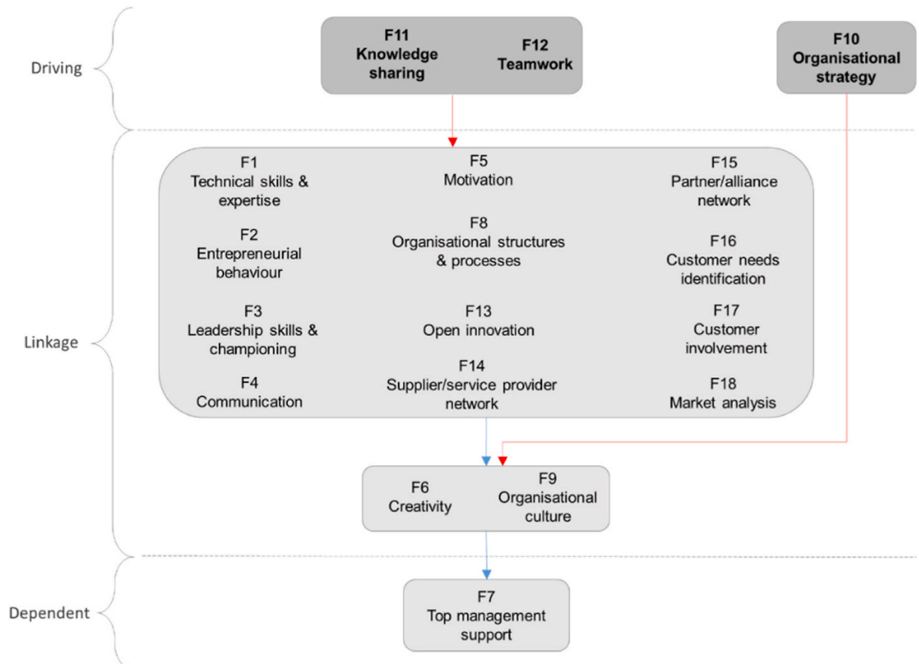

Fig. 4. Product development stage: Interrelated success factors.

require metallurgical engineers, process modellers, mechanical engineers, electrical and control engineers, drafting technicians, civil and structural engineers, and external contractors. The customer will likely be more involved during this stage, giving input and guidance and testing prototypes. These aspects require extensive *teamwork* and *knowledge sharing*, which are the most influential factors of this stage, and they should receive primary attention. These two factors have the same driving power and dependence and influence each other equally. If both factors are managed well, they will enhance the other factors in the product development stage. However, given the bidirectional relationship shared between them, if just one factor suffers, it will also negatively impact the other.

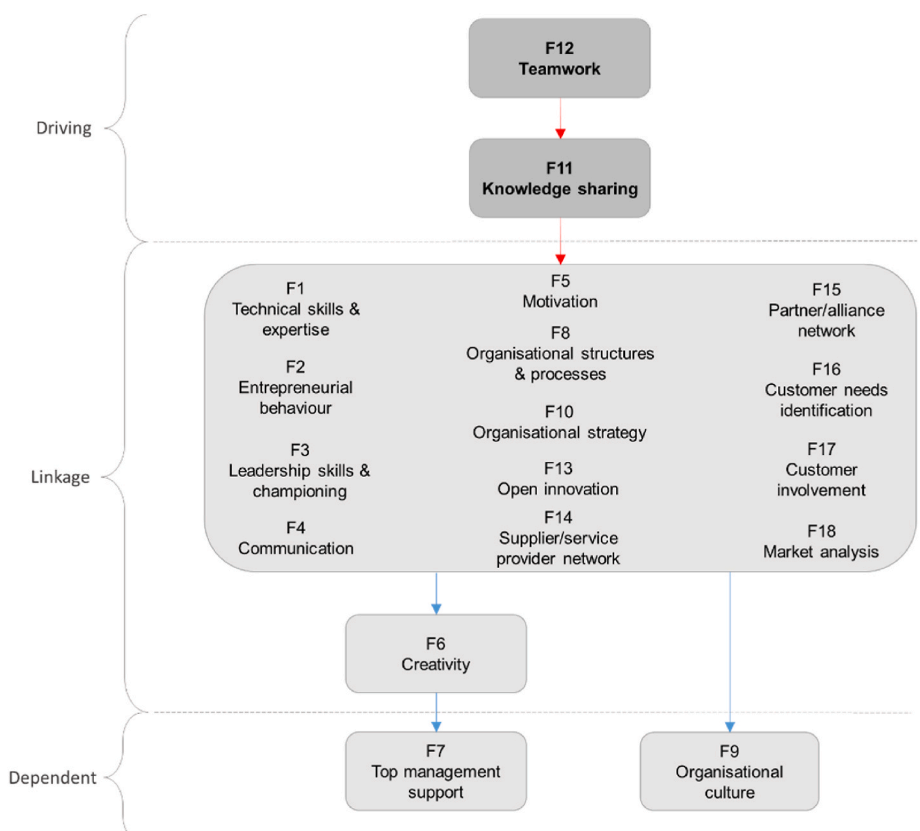

Fig. 5. Implementation stage: Interrelated success factors.

The third driving factor in the product development stage is the *organisational strategy*. Similar to the previous two stages, this factor operates independently of the other driving factors and is not influenced by them. The organisational strategy occupies a unique position in Fig. 4, as it has a direct, one-directional influence on creativity and on the organisational culture, and indirectly influences top management support through creativity and culture. The factors that the organisational strategy does not influence include technical skills and expertise, motivation, communication, and customer needs identification and involvement, among others. It is possible that these factors operate under different constraints, such as engineering design and construction protocols and standards, market requirements, or customer specifications. If this is the case, innovation managers should ensure that the team is fully aware of the relevant protocols, standards, policies, and legislation and that these are applied appropriately to guide the product development efforts towards successful completion.

4.4. Implementation stage

The interrelated success factors for the implementation stage are shown in Fig. 5. Technology implementation, commercialisation or transfer can occur when the development of the technology is complete to such an extent that it is suitable for the implementer or customer to use (Dean et al., 1990).

During this stage, team members from many different departments work together to ensure that all technical aspects are integrated effectively for the technology to function correctly in its intended environment. In certain instances, site preparation work needs to be completed by the civil engineers before the mechanical and process engineers can install the technology. Operations personnel need to receive training and safety briefings, and quality assessments need to be conducted before the initial stages of commissioning can be performed. Implementation involves a multitude of activities that need to be planned, coordinated, and managed. This requires effective *teamwork*. Teamwork is the primary driver of the implementation stage. Of all the innovation stages and factors that are evaluated, teamwork during implementation is the most influential factor.

Fig. 5 illustrates how efficient teamwork promotes knowledge sharing during technology implementation. Proper integration of work by different disciplines is crucial in this stage, which typically involves multiple external contractors and the use of specialised instrumentation and equipment from suppliers or service providers. Moreover, the customer's involvement in the implementation phase is essential as the technology is handed over to the customer for use. Effective knowledge sharing is therefore critical to ensure that the technology is implemented in a safe, reliable, and timely manner while meeting the client's needs.

Fostering teamwork in an organisation has the potential to reap substantial benefits. In 1999, Steve Jobs was the CEO of Pixar (O'Reilly, 2011). Before the concept of open-plan offices was commonplace, Jobs transformed the workspace at Pixar. Up to that time, work areas were generally divided according to disciplines; however, Jobs created a large central atrium with gathering spaces, theatres and break rooms so that people from different disciplines could engage freely with others (Rao et al., 2008). As a result, creativity and collaboration at Pixar increased considerably, and the company released 26 animated feature films, earning 23 Oscars during that time (Catmull, 2008). Opening up silos and allowing people to share ideas across disciplines facilitates innovation and agility within an organisation by encouraging teamwork (Prescott et al., 2012).

The first and second objectives of this study were addressed and discussed in this section, and it was contextualised how the determination of interrelationships between success factors reduced uncertainty associated with managing each innovation stage. For each innovation process stage, managerial uncertainty had been reduced regarding the way success factors are connected as well as their ranking order. In the absence of this information, when evaluating 18 success factors per stage, an innovation manager would be faced with 1.304×10^{92} possible relationships that could exist between the factors. By applying ISM and MICMAC, this study managed to decrease the managerial uncertainty linked to an overwhelming number of potential interrelationships – specifically, 5.215×10^{92} options across the four stages of the innovation process – by identifying the directional relationships between the factors for each stage. The study also reduced the managerial uncertainty associated with 2.561×10^{16} ranking options across the four stages of the innovation process, further improving the understanding of the management of the innovation process stages.

5. Conclusions

When assessing the interrelationships that exist between success factors for the concept development stage, it was determined that the market analysis is the primary driving factor, which influences knowledge sharing. The organisational strategy was also identified as a driving factor, albeit disconnected from the other two drivers. Evaluating a single interrelationship diagram, with the implications relevant to the context within which it was evaluated, is comparable to publications such as Jyoti et al. (2010), Sushil (2018), and Sag et al. (2019), where ISM and MICMAC were applied, and a single interrelationship diagram was generated to represent an entire process. However, this research demonstrates that the interrelations between success factors are not identical across all the stages. For example, when the market analysis is compared, it is shown that this factor becomes less influential across the innovation stages. The market analysis is the primary driving factor during the stages of concept- and technology development; however, its influence decreases during product development and implementation, possibly due to the cost of technological changes becoming too great and opportunities for rapid reaction to market changes become limited. Similarly, when teamwork is compared, it is shown that its influence increases steadily across the stages. Initially, teamwork is not a driving factor, however, its influence increases to being influenced one-directionally by the market analysis in the technology development stage, then bi-directionally with knowledge sharing in product development, and lastly, it is the primary driving factor during implementation. Such a comparison – the dynamics of the influence of the factors across the stages – is possible for all the success factors evaluated for this study because: (i) the same set of success factors was evaluated during each stage and (ii) the interrelationships that exist between the factors were determined for each stage. When compared to literature, none of these insights are possible, since publications have only evaluated a single set of interrelationships for an entire process, without considering the dynamic nature of success factors within the distinct stages.

The results from this study have significant implications for policy makers. Most prominently, is the demonstrated need for customised managerial strategies for the distinct stages of the innovation process. By applying ISM and MICMAC for each stage and identifying distinct driving factors and their ranking within each stage, uncertainty has been reduced regarding which factors required primary attention when managing the various stages. As a result, innovation managers can now develop tailored approaches to effectively manage each stage of the innovation process. Up to now, publications have attempted to reduce uncertainty by evaluating interrelationships between success factors within the context of an innovation process; however, literature does not address the dynamic nature of the success factors across the stages. This research has proven that stage-specific managerial strategies are required to effectively reduce uncertainty when managing each stage of the innovation process. The approach applied in this study could be formalised by policy makers into a technique to assess how innovation is managed in an organisation. The application of ISM and MICMAC has been shown to effectively determine how success factors are connected and their ranking order in each process stage. Within different settings, the application of ISM and MICMAC could generate bespoke results that allow for context-specific interpretation.

The identification of strengths and weaknesses in the innovation management practices can assist in the formulation of strategic improvement interventions. In the concept development stage, market analysis was found to be a driving factor. Having information about how the trends, changes, and needs from the market drive the way innovation is managed during the concept development stage is a strength in the way the stage is managed. Similarly, the driving influence of the organisational culture during the technology development stage is another strength associated with how innovation is managed. However, a weakness was identified in the lack of influence of top management support during the technology development, product development, and implementation stages. Identifying this weakness enables the organisation to develop interventions to improve the influence of top management support as a facilitator of innovation success. Within the RTO, the management of innovation lies with the technical departments. The executives within this organisation follow a "bottom-up" approach to innovation management, which means that the onus for the management of innovation lies with the technical divisions. While this could put the technical departments in a vulnerable position, it also presents a situation of empowerment, where the technical departments have the freedom to pursue innovation opportunities where a need is identified and where the impact could be delivered. A policy to address the vulnerability of such a "bottom-up" approach could be for the innovation team to ensure that whichever innovations are pursued, alignment with the organisational strategy (driving factor) needs to be attained. Furthermore, wherever possible, expectations of top management, and alignment thereof with the innovation activities within the technical departments, need to receive adequate attention. Recognising this weakness allows the organisation to develop interventions to improve the influence of top management support as a facilitator of innovation success.

The strengths of this research include the ability to reduce uncertainty associated with managing innovation by identifying how success factors are connected, as well as their ranking order, in each innovation stage. A further strength of this study is the enablement of the identification of good and poor innovation management practices, as well as the formulation of strategic interventions toward improvement. The results from this research have implications for policy makers, most notably the importance of a stage-specific managerial strategy that is required, and the relevant tools, such as the technique applied in this study, to enable an appropriate innovation management assessment.

There is, however, a weakness related to the study. Applying ISM from first principles can be challenging and cumbersome, especially when a large collection of success factors is evaluated. Software such as the program developed by Broome and Hogan (2020), could assist in simplifying the calculations; however, a foundational understanding of the success factors and the ISM principles would be required. Therefore, while the outcomes of ISM and MICMAC are valuable, the generation of the results is not a straightforward process. Furthermore, the application of ISM proved to be an appropriate methodology for identifying the interrelationships between factors; however, ISM-based models are not statistically verified. Structural equation modelling (SEM) could be applied to determine the magnitude of the relationships between the factors and to test the models statistically. Lastly, while this study focused on the interrelationships that exist between success factors within each stage of the innovation process and made a valuable contribution to the field, it is important to note that there is a need for parallel project management processes, such as time and resource management (Project Management Institute, 2001), which does not form part of the scope of this study.

Future work

A contribution to innovation practice is made by enabling a thorough assessment of how innovation is managed in each process stage. The approach followed for this research could be formalised into a technique for assessing technology innovation management in an organisation. This study showed that the interrelationships between the success factors differed across the process stages for a particular unit of analysis in an organisation. It is recommended that the approach (ISM and MICMAC for each process stage) be replicated in a different case. This would determine whether there were any differences in how innovation is managed in the organisation and determine the versatility and potentially generalised applicability of the technique in other settings.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssaho.2023.100771.

References

Abetti, P. A. (2000). Critical success factors for radical technological innovation: A five case study. *Creativity and Innovation Management, 9*(4), 208–221.

Allen, S., Graupera, V., & Lundrigan, L. (2010). *Pro smartphone cross-platform development: iPhone, blackberry, windows mobile and android development and distribution*. Apress.

Amoroso, S., Moncada-Paternò-Castello, P., & Vezzani, A. (2017). R&D profitability: The role of risk and knightian uncertainty. *Small Business Economics, 48*(2), 331–343.

Azarmi, D. (2016). Factors affecting technology innovation and its commercialisation in firms. *Modern Applied Science,* 36–48.

Balachandra, R., & Friar, J. H. (1997). Factors for success in R&D projects and new product innovation: A contextual framework. *IEEE Transactions on Engineering Management, 44*(3), 276–287.

Balbontin, A., Yazdani, B., Cooper, R., & Souder, W. E. (1999). New product development success factors in American and British firms. *International Journal of Technology Management, 17*(3), 259–280.

Berkhout, A., Hartmann, D., Van Der Duin, P., & Ortt, R. (2006). Innovating the innovation process. *International Journal of Technology Management, 34*(3–4), 390–404.

Bout, L. Y., Lombaers, J. H. M., Fisscher, O. A. M., & Constantinides, E. (2004). Post-Project Reviews as a tool for stimulating commercialisation of knowledge creation projects at TNO Industrial Technology. *R&d Management,* 1–8.

Broome, B., & Hogan, M. (2020). *ISM software free windows download. In freeware*. Available: https://www.jnwarfield.com/ism-software.html https://www.jnwarfield.com/ism-software.html.

Catmull, E. (2008). *How Pixar fosters collective creativity*. MA: Harvard Business School Publishing Boston.

Cetindamar, D., Phaal, R., & Probert, D. (2009). Understanding technology management as a dynamic capability: A framework for technology management activities. *Technovation, 29*(4), 237–246.

Cetindamar, D., Phaal, R., & Probert, D. (2010). *Technology management activities and tools* (Vol. 1). Palgrave MacMillan.

Chalupnik, M. J., Wynn, D. C., & Clarkson, P. J. (2009). *Approaches to mitigate the impact of uncertainty in development processes [Conference], 24–27 August*. Stanford, CA, USA: International Conference on Engineering Design.

Chiesa, V. (2001). *R&D strategy & organisation: Managing technical change in dynamic contexts* (Vol. 5). World Scientific.

Christensen, C., & Raynor, M. (2013). *The innovator's solution: Creating and sustaining successful growth*. Harvard Business Publishing.

Claessens, B. J., Van Eerde, W., Rutte, C. G., & Roe, R. A. (2010). Things to do today…: A daily diary study on task completion at work. *Applied Psychology, 59*(2), 273–295.

Connell, J., Edgar, G. C., Olex, B., Scholl, R., Shulman, T., & Tietjen, R. (2001). Troubling successes and good failures: Successful new product development requires five critical factors. *Engineering Management Journal, 13*(4), 35–39.

Cooper, R. G. (2007). Managing technology development projects. *IEEE Engineering Management Review, 35*(1), 67–76.

Cozijnsen, A. J., Vrakking, W. J., & van Ijzerloo, M. (2000). Success and failure of 50 innovation projects in Dutch companies. *European Journal of Innovation Management, 3*(3), 150–159.

Cummings, J. L., & Teng, B.-S. (2003). Transferring R&D knowledge: The key factors affecting knowledge transfer success. *Journal of Engineering and Technology Management, 20*(1), 39–68.

Dandage, R. V., Mantha, S. S., Rane, S. B., & Bhoola, V. (2018). Analysis of interactions among barriers in project risk management. *Journal of Industrial Engineering International, 14*(1), 153–169.

Dean, J. W., Susman, G. I., & Porter, P. S. (1990). Technical, economic and political factors in advanced manufacturing technology implementation. *Journal of Engineering and Technology Management, 7*(2), 129–144.

Denning, S. (2011). *How do you change an organisational culture?* [Electronic article]. Forbes, Leadership Strategy(July 23, 2011). Retrieved 03 February 2021, from https://www.forbes.com/sites/stevedenning/2011/07/23/how-do-you-change-an-organizational-culture/?sh=45c0d7d039dc.

Dizikes, P. (2010). *Explained: Kightian uncertainty*. MIT News (June 2, 2010).

Elmsalmi, M., & Hachicha, W. (2013). Risks prioritization in global supply networks using MICMAC method: A real case study. In *2013 international conference on advanced logistics and transport*.

Ensminger, D. C., Surry, D. W., Porter, B. E., & Wright, D. (2004). Factors contributing to the successful implementation of technology innovations. *Journal of Educational Technology & Society, 7*(3), 61–72.

Furr, N., & Dyer, J. (2020). Lessons from Tesla's approach to innovation. *Harvard Business Review Strategy*, 1–8 (February 12).

FXSSI.com. (2021). *Most valuable Companies in the world - 2021. FXSSI.com*. Retrieved 04 May from https://fxssi.com/top-10-most-valuable-companies-in-the-world.

Gales, L., & Mansour-Cole, D. (1995). User involvement in innovation projects: Toward an information processing model. *Journal of Engineering and Technology Management, 12*(1–2), 77–109.

Goleman, D. (1995). *Emotional Intelligence - why it can matter more than IQ*. Bantam Books.

Guo, Z., Li, Y., & Stevens, K. J. (2012). Analyzing students' technology use motivations: An interpretive structural modeling approach. *Communications of the Association for Information Systems, 30*(14), 199–224.

Hao, X. J., van Ark, B., & Ozyildirim, A. (2017). Signposts of innovation: A review of innovation metrics. *The Conference Board Economics Program Working Paper, 17*(1), 1–36.

Hempel, J. (2010). How blackberry does it. *Strategic Direction, 26*(2), 7.

Hengsberger, A. (2018). *Four reasons why innovations fail. LEAD Innovation Management GmbH*. Retrieved 23 April from https://www.lead-innovation.com/english-blog/why-innovations-fail#:~:text=Studies%20show%20that%20around%2060%20to%2080%25%20of%20new%20products%20fail.

Iamratanakul, S., Patanakul, P., & Milosevic, D. (2008). Innovation and factors affecting the success of NPD projects: Literature explorations and descriptions. *International Journal of Management Science and Engineering Management, 3*(3), 176–189.

Insights, D. (2020). *Tech trends 2021*. Deloitte Development LLC. Retrieved 29 January from https://www2.deloitte.com/us/en/insights/focus/tech-trends.html.

Ismail, N., Nor, M. J. M., & Sidek, S. (2015). A framework for a successful research products commercialisation: A case of Malaysian academic researchers. *Procedia - Social and Behavioral Sciences, 195*, 283–292.

ISO. (2020). *Innovation management in Fundamentals and vocabolary* (Vol. 56000, p. 2020). Geneve, Switzerland: International Organisation for Standardization.

Jadhav, J. R., Mantha, S., & Rane, S. B. (2014). Development of framework for sustainable lean implementation: An ISM approach. *Journal of Industrial Engineering International, 10*(72), 1–27.

Jalonen, H. (2012). The uncertainty of innovation: A systematic review of the literature. *Journal of Management Research, 4*(1), 1.

Jensen, B., & Harmsen, H. (2001). Implementation of success factors in new product development–the missing links? *European Journal of Innovation Management, 4*(1), 37–52.

Jyoti, T., Banwet, D. K., & Deshmukh, S. G. (2010). Modelling the success factors for national R&D organizations: A case of India. *Journal of Modelling in Management, 5*(2), 158–175.

Kachouie, R., & Sedighadeli, S. (2015). New product development success factors in prospector organisations; mixed method approach. *International Journal of Innovation Management, 19*(4), Article 1550040.

Knight, F. H. (1921). *Risk, uncertainty and profit* (Vol. 31). Houghton Mifflin.

Košturiak, J. (2010). Innovations and knowledge management. *Human Systems Management, 29*(1), 51–63.

Kumar Srivastava, A., & Sushil. (2014). Modelling drivers of adapt for effective strategy execution. *The Learning Organization, 21*(6), 369–391.

Lester, D. H. (1998). Critical success factors for new product development. *Research-Technology Management, 41*(1), 36–43.

Malek, K., Maine, E., & McCarthy, I. P. (2014). A typology of clean technology commercialization accelerators. *Journal of Engineering and Technology Management, 32*, 26–39.

Mazdeh, M., Shafia, M., Bandarian, R., & Kahrizi, A. (2015). An ISM approach for analyzing the factors in technology transfer. *Decision Science Letters, 4*(3), 335–348.

Merriam-Webster Dictionary. (2021). Merriam-webster dictionary. In *Merriam-webster online dictionary*. https://www.merriam-webster.com/thesaurus.

Meyer, E. (2014). *The culture map: Breaking through the invisible boundaries of global business*. PublicAffairs.

Moussi, A., & van Amsterdam, U. (2017). *Mini-case study: The downfall of blackberry* (Vol. 5, p. 24). Universteit van Amsterdam.

Nellore, R., & Balachandra, R. (2001). Factors influencing success in integrated product development (IPD) projects. *IEEE Transactions on Engineering Management, 48*(2), 164–174.

Nowotny, H. (2015). The radical openness of science and innovation: Why uncertainty is inherent in the openness towards the future. *EMBO Reports, 16*(12), 1601–1604. https://doi.org/10.15252/embr.201541546

O'Reilly, T. (2011). Steve Jobs (1955–2011). *Nature, 479*(7371), 42-42.

Prescott, D., El-Sakran, T., Albasha, L., Aloul, F., & Al-Assaf, Y. (2012). Teambuilding, innovation and the engineering communication interface. *American Journal of Engineering Education, 3*(1), 29–40.

Project Management Institute. (2001). Project management body of knowledge (PMBOK® guide). In *A guide to the project management body of knowledge (Vol. ANSI/PMI 99-001-2008)*. Newton Square, PA: Project Management Institute, Inc.

Rajan, R., Dhir, S., & Sushil. (2020). Technology management for innovation in organizations: An argumentation-based modified TISM approach. *Benchmarking: An International Journal, 26*(6), 1959–1986. https://doi.org/10.1108/BIJ-01-2020-0019

Rao, H., Sutton, R., & Webb, A. P. (2008). *Innovation lessons from pixar: An interview with oscar-winning director brad bird* (Vol. 5).

Raz, T., Shenhar, A. J., & Dvir, D. (2002). Risk management, project success, and technological uncertainty. *R&d Management, 32*(2), 101–109.

Rizvi, N. U., Kashiramka, S., Singh, S., & Sushil. (2019). A hierarchical model of the determinants of non-performing assets in banks: An ISM and MICMAC approach. *Applied Economics, 51*(35), 3834–3854.

Romano, C. A. (1990). Identifying factors which influence product innovation: A case study approach. *Journal of Management Studies, 27*(1), 75–95.

van Rooyen, M., van der Lingen, E., & Ross, V. (2020). *Success Factors of technology innovation: An organisational perspective [conference]. 31st annual southern african Institute of industrial engineering conference*. Virtual Event.

Rothwell, R. (1974). Factors for success in industrial innovation. *Journal of General Management, 2*(2), 57–65.

Sag, S., Sezen, B., & Alpkan, L. (2019). Determinants of open innovation and their interrelations. *International Journal of Innovation and Technology Management, 16*(4), Article 1940001.

Samuelsson, J., & Skoglund, L. (2020). *Uncertainty in process innovations: A case study on the adaption of search engine optimisation*. Sweden: Jonkoping University.

Saunders, M., Lewis, P., & Thornhill, A. (2016). *Research methods for business students* (7th ed. ed.). Pearson Education Limited.

Sushil. (2012). Interpreting the interpretive structural model. *Global Journal of Flexible Systems Management, 13*(2), 87–106.

Sushil. (2018). How to check correctness of total interpretive structural models? *Annals of Operations Research, 270*(1–2), 473–487.

Tarka, P. (2018). An overview of structural equation modeling: Its beginnings, historical development, usefulness and controversies in the social sciences. *Quality and Quantity, 52*(1), 313–354. https://doi.org/10.1007/s11135-017-0469-8

Tidd, J., & Bessant, J. R. (2020). *Managing innovation: Integrating technological, market and organizational change*. John Wiley & Sons.

Tidd, J., Bessant, J., & Pavitt, K. (1997). *Managing innovation*. John Wiley&Sons, Ltd.

Trivedi, P. D. (2010). *Consumer dictates the market: Lesson from blackberry* (Vol. 2).

Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychological Bulletin, 63*(6), 384–399.

Tung, L. (2022). *End of a smartphone era as BlackBerry phone reach end of line [Electronic Article]. Innovation(January 4, 2022)*. Retrieved 20 June 2022, from https://www.zdnet.com/article/end-of-a-smartphone-era-as-blackberry-phones-reach-the-end-of-the-line/.

Vance, A., & Sanders, F. (2015). *Elon musk*. HarperCollins.

Van der Heiden, P., Pohl, C., Mansor, S., & Van Genderen, J. (2016). Necessitated absorptive capacity and metaroutines in international technology transfer: A new model. *Journal of Engineering and Technology Management, 41*, 65–78.

Verhaeghe, A., & Kfir, R. (2002). Managing innovation in a knowledge intensive technology organisation (KITO). *R&d Management, 32*(5), 409–417.

Walker, B., & Soule, S. A. (2017). Changing company culture requires a movement, not a mandate [Electronic Article]. In *Harvard business review*. *Leadership*(June 20, 2017). Retrieved 03 February 2021, from https://hbr.org/2017/06/changing-company-culture-requires-a-movement-not-a-mandate.

Walter, A. (2003). Relationship-specific factors influencing supplier involvement in customer new product development. *Journal of Business Research, 56*(9), 721–733.

Wang, M., Wu, C., Chen, R., Chen, W., & Liu, C. (2014). An ISM based approach for product innovation using a synthesized process. *Mathematical Problems in Engineering, 2014*, 1–12. Article 341614.

Yong, A. G., & Pearce, S. (2013). A beginner's guide to factor analysis: Focusing on exploratory factor analysis. *Tutorials in quantitative methods for psychology, 9*(2), 79–94.

Zirger, B. J., & Hartley, J. L. (1994). A conceptual model of product development cycle time. *Journal of Engineering and Technology Management, 11*(3–4), 229–251.