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Contextual Analysis of Innovation Process Models toward the Fourth Industrial Revolution

Ambika Koonj Beharry [a,Ψ,] and Kit Fai Pun [b]

Department of Mechanical and Manufacturing Engineering, The University of the West Indies, St Augustine, Trinidad and Tobago; West Indies.

[a]Email: Ambika.KoonjBeharry@sta.uwi.edu
[b]Email: KitFai.Pun@sta.uwi.edu.

[Ψ] *Corresponding Author*

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Abstract: *Innovation is a contextual subject drawing from a multiplicity of perspectives with applications. This paper presents the taxonomies of innovation, explores the innovation-industrialisation relationship, and relates the evolution of innovation concepts to various phases of industrial revolutions. Advocates and features of nine (9) innovation process models in the innovation literature are analysed, and a comparative analysis of innovation processes is made. The analysis compares the different stages of the innovation process as advocated in respective models, and identifies their main contextual themes and sub-themes which serve as antecedents to innovation emerging from a firm-level perspective. Five contextual themes emerge from the analysis – 1) strategy; 2) management; 3) organisational culture; 4) organisational learning and 5) communication. Within each theme, several endogenous factors were identified based on their frequency of occurrence in these models. The most common factors, with a frequency of six or more, were found to be: from the strategy domain, customer-centric focus, market orientation and future-orientation; from the management domain, support for innovation and from the communication domain, inter-firm communication. This paper provides a chronological review of the nine innovation process models, in relation to innovation-industrialisation relationship and implications for operating in the fourth industrial revolution. It contributes to identify the contextual themes and factors of innovation process models with organisational learning at the firm's level. Future studies would examine the contextual themes of innovation process in organisations towards technology transfer and organisational learning, across various industry sectors in selected nation(s).*

Keywords: *Industrial revolutions, innovation processes, firm-level perspective, factors*

1. Introduction

The etymology of the word 'innovation' dates back to the mid-fifteenth century. The Etymology Dictionary traces the origin of the word from the Late Latin 'innovationem', a noun of action which stems from the past participle 'innovare' meaning 'to change or to renew'. Another school of thought attributes the origin to the Latin 'novus' which translates as 'new' (Bagherinejad, 2006). There exists no universally accepted definition of the term 'innovation'. Existing definitions of innovation are as diverse as the disciplines that put forward an explanation of the concept, and are therefore influenced by the context of its origin (Srivastava, 2015).

Garcia and Calantone (2002) assert that the plethora of definitions of the concept lead to ambiguity in its utilisation in the literature and its operationalisation in empirical research. Crossan and Apaydin (2010) propose a 'multi-level approach' across societal, organisational and individual levels, due to lack of a singular theory which could operate at all levels simultaneously. The diverse streams of innovation research have led to the consideration of innovation across multiple domains (Avermaete et al. 2003). Innovation models have evolved over time and represent the range of activities undertaken during the innovation process. This paper explores the recurring contextual themes based on a comparative analysis of innovation models and processes advocated in literature. The key stages and elements of innovation processes at the firm's level are explored and their implications for firms operating in the fourth industrial revolution are discussed.

2. Taxonomies of Innovation

2.1 The Multi-Disciplinary Thinking

The multi-disciplinary approach explores innovation through the lens of individual disciplinary specialisations. According to Godin (2008), from a technological perspective, German economist, Joseph Schumpeter, regarded as a pioneer in the field of innovation theory, defines innovation as "*a new combination of means of production, that is, as a change in the factors of production (inputs) to produce products (outputs).*" From a developmental perspective, Arais-

Aranda et al. (2001) define innovation as "*the creative process through which new products, services or production processes are developed*". From a knowledge perspective, du Plessis (2007) defines innovation as "*the creation of new knowledge and ideas to facilitate new business outcomes, aimed at improving internal business processes and structures and to create market driven products and services*". From a team-based perspective, Goyal and Akhilesh (2007) define innovation as "*the successful implementation of creative ideas within an organisation* [whereby] *creativity from individuals and teams serves as a starting point for innovation*".

Laforet and Tann (2006) noted the existence of three streams in innovation research. The first stream is the economic-oriented stream which highlights the importance of small and medium-sized enterprises (SMEs) as a driving force for innovation and being equally innovative as larger firms. The second stream is the organisation-oriented stream which prescribed a number of organisational factors that small business owners could use to enhance organisational performance, and the third stream is the project-oriented stream which viewed customers as important sources of innovation.

In comparing the main streams of innovation, similarities are found between 1) the developmental perspective and the economic-oriented stream which focus on innovation processes of firms, 2) the knowledge perspective and the organisation-oriented stream which concentrate on knowledge sharing activities within the organisation, and 3) the team-based perspective and the project-oriented stream which are people-based approaches to innovation. There exists a link between the streams of innovation research and the perspective definitions of innovation. Across all streams/disciplines, organisational learning is implicitly practiced though not necessarily explicitly managed.

2.2 The Multi-Dimensional Thinking

From the multi-dimensional thinking, innovation examines the impact on various strata that result from changes in the operational characteristics of a firm. According to Schumpeter (1934), these "new combinations" lead to innovation in five (5) distinct dimensions, namely, product, process, market, source and organisation. Similarly, the OECD (2005) Oslo Manual (3rd Ed.) considers innovation along four dimensions brought about through "changes in its methods of work, its use of factors of production and the types of output that improve its productivity and/or commercial performance.

Several distinctions of the dimensions are observed. Firstly, the Oslo Manual extends Schumpeter's definition of 'product innovation' to include services. Secondly, the Oslo Manual's definition of 'process innovation' includes methods of delivery unlike Schumpeter who focused primarily on methods of production. Thirdly, Schumpeter considers 'market innovation' *vis-a-vis* the Oslo Manual's 'marketing innovation' which focuses on marketing as a means to new markets. Fourthly, Schumpeter looks at 'organisation innovation' from an inter-firm perspective, while the Oslo Manual looks at 'organisational innovation' which includes intra-firm operations of the organisation. Finally, unlike Schumpeter, the Oslo Manual does not consider 'source innovation'.

The Oslo Manual largely concurs with Lundvall's (1992) definition (as cited by Avermaete et al, 2003) which states that innovation is an ongoing process of leaving, searching and exploring which results in: (1) new products; (2) new techniques; (3) new forms of organisation; and (4) new markets. Moreover, Tidd et al. (2005) propose the '4Ps' of innovation from the perspective of 'change' along the four (4) dimensions, as follows:

1. *Product* – Change in the product/service offered
2. *Process* – Change in the methods of creation and delivery
3. *Position* – Change in the target market/market strategy
4. *Paradigm* – Change in the operational intention

The dual concepts of 'new' and 'change' are explained by two distinct modes of innovation espoused in the literature namely, radical innovation and incremental innovation (Lin and Chen, 2007; Zhao, 2005). Oke et al. (2007) define radical innovation from a market perspective as the introduction of a new product to an existing market and the introduction of a new product to a new market whereas they define incremental innovation from a product perspective as minor and major improvements to existing products.

2.3 The Process Thinking

The process thinking toward defining innovation considers all activities along the "innovation value chain" (Hansen and Birkinshaw, 2007). Kline and Rosenberg (1986) assert that innovation is a non-linear process owing to its susceptibility to various change factors. Tidd et al. (2005) agree that a linear approach to innovation simplifies the complexities arising from interaction between 'technology push' and 'need pull' activities.

Moreover, Cumming (1998) asserts that there are three basic steps in the innovation process starting with the idea generation followed by successful development of the idea into a useable concept and culminating in successful application of the concept. Ahmed (1998) describes innovation as a three-phase process, starting with idea generation progressing onto idea validation and ending with commercialisation. Similarly, Hansen and Birkinshaw (2007) propose that innovation is an "integrated flow" across the three phases of idea generation, conversion and diffusion. The idea of integrated flow is affirmed by Roper et al. (2008) who consider innovation as an intermediary event linking

precursory knowledge management activities and preceding value creation activities.

3. Evolution of Innovation Concepts across the Four Industrial Revolutions

Regardless of the innovation context, technological innovations have been the driving force of industrialisation. This is evidenced by four (4) major technological breakthroughs that have influenced the mode of production in the global manufacturing sector (Naudé, and Adam Szirmai, 2012). These developments have led to the successive progression of four (4) industrial revolutions since the second half of the eighteenth century. Figure 1 maps the innovation-industrialisation relationship from the perspective of technological innovation leading industrialisation.

The Fourth Industrial Revolution (4IR) brings with it a unique set of opportunities and challenges which have significant implications for industry, labour and governments (Schwab, 2016). While technological innovations have set the pace for industrialisation, the converse is also true. Industrialisation has in turn stimulated innovation in the form of emerging technologies and technological developments (Schwab, 2016), resulting from new combinations of technologies (Lee et al., 2018; Nicolov and Badulescu, 2012).

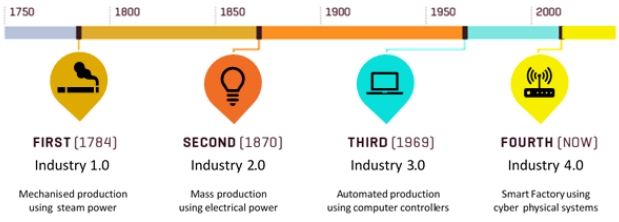

Figure 1. Mapping of the Innovation-Industrialisation Relationship

According to Verloop (2004), innovation during the pre-industrial era was *ad-hoc* and lacked scientific and technological applications. The onset of the industrial era changed the innovation landscape by introducing technology-driven processes which have since transitioned into opportunity-driven processes. Opportunity-driven innovation is the mainstay of the 4IR resulting from exponential increase in speed and scope of impact from technological breakthroughs (Schwab, 2016).

Rothwell's (1994) seminal work on the 'fifth-generation innovation' concept has pioneered the characterisation of innovation models throughout the industrial era (Hobday, 2005; Tidd, 2006). Based on his classification, innovation was considered as a linear process during the first and second generations however, the focus of the first generation was on technological development (technology-push) while in the second-generation emphasis was placed on market demand (need-pull). The third-generation innovation process saw a "coupling" of the push-pull factors along a "*logically sequential, though not necessarily continuous process, that can be divided into a series of functionally distinct but interacting and interdependent stages*" (Rothwell, 1994).

However, Hobday (2005) argues that the transition from one generation to the other does not imply a discontinuation of models from the previous generation but rather an expansion of models that co-exist and intersperse. This is evident in the disparity between developing and developed economies. Innovation in developing countries, such as the Caribbean, emerges from "behind the technology frontier" as defined by leading industrially advanced countries (IACs). Hobday (2005) asserts that innovation process models across these five generations are presented from the perspective of the research and development (R&D)/technology developers, usually from the developed economies, and does not take into account the distinct innovation process of R&D/technology adopters, such as the developing countries. Marinova and Phillimore (2003) build upon Rothwell's (1994) five generations of innovation models by broadening Rothwell's typology and introducing a sixth generation of innovation. The scope of Rothwell's analysis occurs at the firm level while Marinova and Philimore's analysis extends to the economy level. A decade later, Kotsemir and Meissner (2013) present another perspective on the evolution of innovation models and further extend the classification to include an emerging seventh generation of innovation models.

Chesbrough (2003) pioneered what he termed "the era of open innovation". The major premise of open innovation is the decentralisation, diffusion and distribution of both internal and external R&D capabilities via inflows and outflows of knowledge-based competencies (Chesbrough, 2011). The open innovation model encourages interaction with external R&D networks toward leveraging internal R&D capabilities (Salter et al., 2014) through integrated "technology acquisition" and "technology exploitation" (Van de Vrande, 2009) unlike the first five generations of innovation models which focused primarily on technology development (Hobday, 2005).

Across the generations, innovation models have evolved from single-dimensional models to more complex multi-dimensional models. Eveleens (2010) describes the evolutionary trend of innovation models as becoming more intricate, interdisciplinary and interconnected as a result of the increasing complexity of the operating environment. Single-dimensional models consider the innovation process as a "linear sequence of functional activities", while multi-dimensional models account for the innovation process as a set of interactive cross-functional intra- and inter-firm activities (Tidd et al, 2005).

Based on the timescales presented by Kotsemir and Meissner (2013), the generations of innovation models are superimposed onto the timeline of the four (4) Industrial Revolutions to illustrate the innovation – industrialisation relationship. It is observed that the formalisation of innovation process thinking began toward the end of the technology-driven phase of the industrial era which coincided with the end of the Second Industrial Revolution (2IR), while most of the innovation models classified thus far have emerged during the Third Industrial Revolution (3IR). Marinova and Philimore (2003)'s sixth generation Innovative Milieux model as well as Kotsemir and Meissner (2013)'s seventh generation Open Innovator model transition into the 4IR.

4. Review of Innovation Process Models

This section presents a chronological review of nine (9) innovation models between 1985 and 2007 spanning the 3IR and 4IR. The models are assessed in the context of the 4IR which is characterised by digital transformations integrating technology, market and society (Lee et al., 2018) and the application of the Internet of Things (IoT) to the creation of industrial value (Kiel et al., 2017) via distributed value chains (Lee et al., 2018).

4.1 Rothwell and Zegveld (1985) Coupling Model

During the third generation of innovation processes Rothwell and Zegveld (1985), as cited by Rothwell (1994), present the coupling model of innovation. The coupling model of innovation essentially combined the first- and second-generation innovation processes to account for both technology push and market pull forces. Like its predecessors, the third-generation innovation model was basically a series of sequential but not necessarily continuous stages. A major distinction between the coupling model and its predecessors was the inclusion of intra- and extra-organisational feedback loops. According to Rothwell (1994), success is dependent of efficient management of several project-level and corporate-level factors. Project-level factors include effective communication among all endogenous and exogenous actors in the process, the appointment of idea champions and organisational learning. Corporate-level factors include management support for innovation, flexibility and responsiveness to change and an accommodating culture. Rothwell (1994) stresses the human element at the core of a successful innovation effort.

Key points for consideration

Based on Rothwell and Zegveld's (1985) model, key points that emerge for consideration:
- the need for consideration of both technology push and market pull factors;
- the need for effective communication among all participants in the process;
- the need for management support for innovation and
- the need for competent individuals to champion the initiative.

While Rothwell and Zegveld's (1985) model emerges in the 3IR, it combines two of the three integrated components of the 4IR as identified by Lee et al., (2018) – technology and market. The emphasis on effective communication among actors in the process is enabled by the preponderance of digital technologies in the 4IR.

4.2 Cooper's (1990) Stage-Gate System

Cooper (1990) proposes a linear five-phase stage-gate system built upon a process-management approach. The basis of this model is a focus on the production process toward the removal of variances within the process with the intention of improving the quality of the output. A stage-gate system consists of a series of predefined activity-based stages that take the process from idea to launch. Between each stage is a gate which acts as a checkpoint with specified criteria and deliverables. The use of the checkpoint system creates a linear process and appears to circumvent the need for feedback loops in Cooper's (1990) model. Two caveats are presented in Cooper's (1990) stage-gate system:

1. Stage-gate systems usually range from four to seven stages and gates depending on their specific application and
2. The typical five-stage (five-gate) system can be adapted to model an innovation process by setting appropriate activity-based stages as well as relevant criteria and deliverables at each gate.

Key points for consideration

Based on Cooper's (1990) model, key points that emerge for consideration:
- the need for a flexible system in terms of the number and nature of stages and gates dependent on the application, and
- the need for thorough checkpoints with appropriately defined criteria and deliverables to ensure continuous alignment along the process toward the endpoint.

The operationalisation of distributed networks in the 4IR wherein actors along the value chain function independently within an integrated system (Lee et al., 2018, draws on the need for continuous alignment along the process to ensure the desired outcome is achieved. System flexibility is inherent in the size and composition of the distributed network.

4.3 Ahmed's (1998) Three-Phase Innovation Model

Ahmed (1998) describes innovation as a holistic process comprised of three distinct recurrent and concurrent phases. First is the idea generation phase in which ideas emerge, many of which do not proceed to the second stage. Second is the idea rationalisation phase which utilises an internal control stage-gate system with feedback loops to determine the feasibility of ideas and their compatibility with organisational goals. Ahmed's (1998) model uses a variation of Cooper's (1990) linear stage-gate system by including cyclical feedback loops.

The third and final stage in the process is the commercialisation of the viable idea(s) with the aim of value extraction. The effectiveness of this process depends on the firm's ability to provide the appropriate culture and climate conducive to innovation and stresses that such culture should be aligned with the firm's organisational goals (Ahmed, 1998). This link between innovation culture and organisational goals suggests that characteristics of an innovation culture would be unique to a particular firm.

The culture and climate foster innovativeness. Ahmed (1998) distinguishes culture as "a primary determinant of innovation" and further suggests that positive cultural characteristics are critical to a firm's ability to innovate. This view is substantiated by Allee and Taug (2006), who suggest that Western firms need to inculcate innovativeness in their culture and structure if they are to sustain their competitiveness and growth. The iterative nature of Ahmed's (1998) model suggests that there is room for continuous improvement and refinement of ideas throughout the process. The second stage of this model is critical to successful innovation since an alignment between external environmental factors and organisational strategy is a determinant of organisational performance (Alam, 2006) and the foundation of a robust innovation culture and competitiveness (Ulusoy et al., 2015; Garcia-Morales et al., 2006).

Key points for consideration

Based on Ahmed's (1998) model, key points that emerge for consideration:
- the need for the establishment of a culture that facilitates innovation since appropriate organisational culture is the catalyst for idea generation which is the seed of innovation;
- the need for innovation culture to align with organisational goals in the context of the external operating environment, and
- the need for the innovation process adopted by a firm to allow for continuous improvement and refinement of ideas that are feasible for commercialisation.

The focal point of Ahmed's (1998) innovation model is organisational culture to foster innovation. Among the stated elements of innovation culture is adaptability. The rate of change and span of impact of the 4IR (Schwab, 2016) require organisations to be change tolerant as opposed to change averse and ensure that adequate and appropriate resources are available to respond to changes in the external operating environment (Ahmed, 1998). Schwab (2016) endorses the need for organisations to re-evaluate their culture in light of the changing operational environment.

4.4 Cumming's (1998) Model of Elements for Innovation

Cumming (1998) uses the engineering concept to identify the factors that affect the innovation process. Cumming (1998) expands on the three-stage innovation model discussed by Ahmed (1998) by including the elements required for innovation at each stage. There are some notable differences between these two innovation models. Cumming (1998) justifies the need for an environment that facilitates creativity as this affects the quality and quantity of the ideas generated. However, while Ahmed's second stage seeks to align ideas with organisational goals, Cumming's second stage focuses on refining ideas generated in the first stage directly with the end user in mind. This customer-centric perspective is an example of a market-pull model.

While the final stage of Ahmed's innovation process focuses on value extraction through commercialisation of an idea, the final stage of Cumming's innovation model concentrates on application through market testing in an effort to understand the needs of the customer, so as to avoid premature failure of a potentially feasible idea. Cumming (1998) highlights that gaining an understanding of the customers' needs does not guarantee success of the idea however, a lack of understanding of the customers' needs will almost certainly result in failure of the idea. This suggests that market research and market testing are critical to the innovation process and should be conducted during implementation but before full-scale commercialisation of the idea. While Ahmed (1998) emphasises culture as a key enabler of innovation, Cumming (1998) focuses on technology as the key component to bridge the gap from idea generation to successful implementation.

Key points for consideration

Based on Cumming's (1998) model, key points that emerge for consideration:
- the need for market testing as an important stage in the implementation of a concept before full-scale commercialisation in the market as this ensures that the market is capable of successfully absorbing the innovation;
- the need for feedback and review of 'system errors' and
- the need for technology considerations as a key enabler of the innovation process.

Just over a decade later, Cumming (1998), like Rothwell and Zegveld (1985) return emphasis to technology and market considerations.

4.5 Gaynor's (2002) Four-Stage Systems Model

Gaynor (2002) advocated a four-stage systems model of innovation that is an extension of Cooper's (1990) stage-gate system. The model includes a post-implementation review phase which assimilates the new product into the organisation and terminates the 'project'. This phase also incorporates organisational learning. It considers project management issues as an important ingredient which bridges the gap between concept development and extraction of value from the concept via product launch.

Another notable difference of this model is the elimination of infeasible ideas at the first idea generation stage unlike the previously discussed three-stage models in which 'knockouts' occur during the second idea

development stage. A perceived strength of this model is the distinction between pre-project activities and project activities.

While Ahmed's (1998) model considers commercialisation as the only means of extracting value from the concept, Gaynor's (2002) product launch stage is a more holistic approach to value extraction and considers commercialisation as one factor in this process. Moreover, Gaynor (2002) emphasises the sentiment of culture as an important ingredient in the recipe for successful innovation as suggested by Ahmed (1998) and Cumming (1998). However, unlike Ahmed's (1998) model which has a feedback mechanism at the internal idea development phase, this model considers feedback at the external product launch phase based on end-user response.

Key points for consideration

Based on Gaynor's (2002) model, key points that emerge for consideration:
- the need for consideration of design validation and project management issues as part of the innovation process, and
- the need for customer input to drive product optimisation.

The customer-oriented focus of Gaynor's (2002) model aligns with the evolving role of the customer as the driver of innovation (Schwab, 2016) particularly considering the shortening of the gap between the firm and its customer in a disrupted network (Lee et al., 2018).

4.6. Chesbrough's (2003) Open Innovation Model

Chesbrough (2003, 2012) changed the innovation landscape by introducing his open innovation model resulting in a paradigm shift which opened new vistas for research and development of ideas by transforming the boundary of the firm from a closed rigid structure to an open penetrable structure. The concept of the open innovation model allows firms to capitalise on opportunities beyond its boundaries and limited internal capabilities. This holds true from both the research and development (market) domains. The foundation of the open innovation model is knowledge-sharing within and across firms.

This knowledge-sharing approach allows firms to profit from others' use of their IP as well as from their use of others' IP thereby generating optimal use of internal and external ideas, technologies and markets (Chesbrough, 2003). The open innovation approach would minimise the risk of missed opportunities which occurs when potential ideas do not align with organisational goals. Chesbrough (2003) cites the case of Xerox which failed to capitalise on research in computer hardware and software technologies because they were not aligned with its core competency in printers and copiers.

Moreover, Gassmann and Enkel (2004) propose three archetypes of open innovation processes – 1) the outside-in process which is the integration of external knowledge into internal operations; 2) the inside-out process which involves the transfer of ideas to the external environment and 3) the coupled process combines activities of the outside-in and inside-out processes and requires cooperation among internal and external partners.

Key points for consideration

Based on Chesbrough's (2003) model, key points that emerge for consideration:
- the open innovation model contradicts the notion that ideas worth pursuing should be aligned with organisational goals/strategy;
- the importance of knowledge-sharing between firms, particularly in the Fourth Industrial Revolution where organisational boundaries are becoming less rigidly defined (Schwab, 2016), and
- the need for alliances with other firms to capitalise on a potentially viable idea outside the core competencies of the firm.

Chesbrough's (2003) Open Innovation model comes as a turning point between the 3IR and the 4IR. This model seems to lead the emergence of the distributed network where firms act outside of their boundaries and competencies.

4.7 Tidd et al.'s (2005) Innovation Process Model

Tidd et al. (2005) present an innovation process model which incorporates a number of features models previously discussed. The first stage involves searching and scanning the internal and external environments for new opportunities however, the increasing volume of information being generated can result in 'noise' infiltrating the system and drowning out potentially strong signals. To combat this situation, Tidd et al. (2005) suggest defining a 'search space' to filter potential ideas, and affirm that even resource-endowed firms need to focus on a carefully selected subset of ideas identified through the development of an appropriate strategic framework. This would be guided by analysis, choice and monitoring and a balanced portfolio management strategy that transitions selected projects to the implementation phase.

The first step of the implementation phase is acquisition of appropriate knowledge and technology. This is critical for smaller firms and firms in less IACs such as in the Caribbean (ECLAC, 2012). The next step is execution of the idea in which Tidd et al. (2005) suggest a tailored and structured stage-gate approach based on Cooper (1990). A successfully executed project is now ready for launch. This step, like Cumming (1998), involves extensive preparation and testing to ensure successful absorption by the market, and a final step would be focused on review of the process toward learning (Tidd et al., 2005). However, learning is also stressed at all phases across the process and includes

feedback into the system as supported in other models like Rothwell (1992) and Gaynor (2002).

Key points for consideration

Based on Tidd et al.'s (2005) model, key points that emerge for consideration:
- the need for a well-defined 'search space' and portfolio management strategy and
- the importance of knowledge and technology transfer/acquisition particularly for small firms and less IACs.

Tidd et al.'s (2005) model continues the original focus on technology with emphasis on technology transfer which is of particular importance to small firms and less industrially advanced countries. Technology acquisition provides an avenue for these entities to step into the technology frontier and operate in the 4IR. In turn, 4.0 technologies expand the 'search space' building on Chesbrough's (2003) Open Innovation model and formalising the concept of the distributed network.

4.8 Assink's (2006) Disruptive Innovation Model

Assink (2006) presents a model of innovation based on disruptive innovation as opposed to incremental innovation and focuses on large firms. It is based on the premise that large firms often fail to develop disruptive innovation. Assink (2006) describes disruptive innovation as game-changing with the potential to displace competitors and unveil new prospects for profit growth. This will become increasingly important in the 4IR which is expected to spur unprecedented transformations in the global industry and potentially alter our very existence (Schwab, 2016).

Assink's (2006) disruptive innovation model comprises of four stages - 1) identify; 2) develop; 3) plan and 4) implement. Internal inputs include a range of endogenous factors such as resources, structure and culture while external inputs include exogenous factors from economic, social, political and competitive domains. A distinction is made with Assink's (2006) model however, which comprises of a spiral within the four-stage quadrant structure. This spiral is formed from a series of probing, learning, decision, forward- and backward-feeding loops. These probing, learning and feedback cycles are central to Assink's (2006) disruptive innovation model. This stresses the importance of organisational learning as a key success factor of [disruptive] innovation (Jiménez-Jiménez and Sanz-Valle, 2011).

Points for consideration

Based on Assink's (2006) model, key points that emerge for consideration:
- the importance of organisational learning throughout the innovation process and
- the need for continuous learning and feedback loops throughout the innovation process.

The significance of organisational learning as a key driver of innovation is presented in Assink's (2006) model. Organisational learning continues to play an important role in the context of the 4IR but represents changes in the way knowledge is acquired, transferred and utilised in the era of Big Data (Ediz, 2018). This presents a shift in the cultural orientation of firms as it relates new modalities for knowledge management.

4.9 Hansen and Birkinshaw's (2007) Innovation Value Chain Model

Hansen and Birkinshaw (2007) propose the innovation value chain model which consists of three sequential phases starting with idea generation proceeding to idea development and culminating with idea diffusion. The structure of the innovation value chain model is analogous to that of Ahmed (1998) and Cumming (1998). However, the innovation value chain outlines six management tasks to be undertaken across the process as – 1) internal sourcing; 2) cross-unit sourcing; 3) external sourcing; 4) selection; 5) development and 6) company-wide spread of the idea.

Cumming (1998) identifies several elements that contribute to an effective idea generation phase across various themes however, the focus of the innovation value chain model at this stage is the source of the idea. According to Hansen and Birkinshaw (2007), there needs to be a combination of internal and external sources at both micro- and macro-levels. These include intra- and inter- department levels in tandem with extra- firm and industry levels. They caution against becoming insular, particularly firms that are currently leaders of industry since history has shown that such thinking can be detrimental. Kodak is a prime example (Anthony, 2016).

At the second phase, Cumming (1998) again identifies a range of elements required. However, Hansen and Birkinshaw (2007) narrow it down to an effective combination of screening and funding mechanisms. They highlight the need for balance between these two forces since stringent funding policies can stifle novel ideas while laxed screening can lead to diversion from overall organisational strategy. At the final stage, Cumming (1998) focuses on elements related to the product and customers. However, Hansen and Birkinshw (2007) emphasise the need for buy-in of a feasible idea, not only from the end-user, but also from all sectors within the organisation in order to effectively diffuse the idea throughout the market.

Key points for consideration

Based on Hansen and Birkinshaw's (2007) model, key points that emerge for consideration:
- the need for consideration of internal and external factors at the idea generation phase;
- the need for effective screening and funding mechanisms at the idea conversion phase, and
- need for holistic buy-in at the organisational and customer levels at the idea diffusion phase.

Hansen and Birkinshaw's (2007) model emphasises the need for optimal value creation along the value chain. This in an effort to make optimal use of scarce resources

which, according to Lenart-Gansiniec, (2019), is the genesis for the 4IR.

5. Comparison amongst Innovation Process Models

There is a progression of focus across these innovation process models towards an explicit extraction of the organisational learning concept as a source of innovation. A clear path is observed starting with a focus on the individual then shifting to a focus on the process followed by consideration of culture. This progresses to a focus on the customer/end user which then proceeds to a focus on inter-firm collaboration before culminating with a focus on organisational learning and continuous feedback loops. It comes as no surprise that current models of innovation focus on organisational learning at the onset of the 4IR which is increasingly data driven.

5.1 Stages of the Innovation Process

As depicted in Table 1, the nine (9) innovation models reviewed have processes ranging from three to seven stages. All models start with some form of 'idea generation' and all progress to the 'market' stage which, for seven of the nine models, is the end of the process. However, in two models – Cooper (1990) and Tidd et al. (2005) – there is one stage beyond the market stage which entails review of the process from idea to market which is an essential step toward organisational learning. Divergent views spring from the 'idea development/conversion' stage. While Ahmed (1998), Cumming (1998) and Hansen and Birkinshaw (2007) maintain a broad-based view of the 'idea development/conversion' stage, other models dissect the development stage into distinct phases that range from planning to manufacturing to market testing and marketing activities. Ahmed (1998), Gaynor (2002) and Tidd et al. (2005) adapt the stage-gate approach of Cooper (1990) into the respective development stage of their models.

The processes of each model represent a linear progression from one stage to the other. This holds true for Cooper (1990), Cumming (1998) and Hansen and Birkinshaw (2007), and the other models utilise feedback mechanisms at some point throughout the process. On one hand, feedback occurs at a single point in the process such as Gaynor (2002), where feedback comes at the end of the process while for Ahmed (1998), feedback occurs during the development stage. On the other hand, feedback occurs throughout various stages of the process such as Rothwell and Zegveld (1985), Tidd et al. (2005) and Assink (2006).

5.2 Contextual Themes of Innovation Process Models

Analysis of the innovation process models revealed five themes and fifty-six (56) sub-themes or factors with some recurring among the lot. Table 2 lists the various factors that emerge across the five major themes from analysis of the models reviewed. The major themes span the areas of strategy, management, organisational culture, organisational learning and communication.

Table 1. Nine Representing Models and Stages of the Innovation Process

Representing Models	***Stages of the Innovation Process***						
1. Rothwell and Zegveld (1985)	Idea Generation	Research Design and Development	Prototype production	Manufacturing	Marketing and Sales	Market	
2. Cooper (1990)	Idea	Preliminary Assessment	Detailed Investigating	Development	Testing and Validation	Production and Market launch	Post Implementation Review
3. Ahmed (1998)	Idea Generation	Structured Methodology (Stage-Gate System)				Commercialisation	
4. Cumming (1998)	Birth of the Idea	Successful Development				Successful Application	
5. Gaynor (2002)	Idea Conception	Pre-Project Stage	Project Stage	Project-Product Launch			
6. Chesbrough (2003)	Technology Base		Technology Sourcing			Market	
7. Tidd et al. (2005)	Search	Select	Acquire	Execute		Launch	Sustain
8. Assink (2006)	Idea	Develop	Plan	Implement			
9. Hansen and Birkinshaw (2007)	Idea Generation	Idea Conversion				Idea Diffusion	

Table 2. Contextual Themes of Innovation Process Models

Contextual Theme	*Rothwell & Zegveld (1985)*	*Cooper (1990)*	*Ahmed (1998)*	*Cumming (1998)*	*Gaynor (2002)*	*Chesbrough (2003)*	*Tidd et al. (2005)*	*Assink (2006)*	*Hansen & Birkinshaw (2007)*
Strategy									
Tech-push and Need-pull	X					X			
Inter-function collaboration	X		X		X		X		
Efficient project execution	X								
Quality considerations		X							
Quality-Cost-Time focus				X					
Flexibility	X	X	X				X	X	
Idea champions			X					X	X
HR development	X				X				
Competitor analysis							X		
Portfolio management							X		
Established criteria		X							
Customer-centric	X				X	X	X		
Market orientation, testing	X	X	X		X	X	X	X	X
Pre-development activity		X							
Structured methodology		X	X				X		
Parallel processing		X							
PM approach					X		X		
Leverage competencies								X	
Inter-project synergy	X								
Socio-technical balance			X						
Reduced bureaucracy			X		X			X	X
Corporate philosophy			X		X				
Enabling technology	X			X		X	X		
Process innovation				X					
Materials development				X					
Capital investment			X		X				
Multichannel funding									X
Resource allocation					X		X	X	
Future-oriented			X		X	X	X	X	X
Management									
Support for innovation	X	X	X		X		X	X	
Risk tolerance	X		X				X	X	X
Continuous monitoring									X
Control	X	X							
Organisational culture									
Innovation-oriented	X		X						
Entrepreneurial	X		X						X
Foster creativity	X				X			X	
Effective problem-solving					X				X
Worker autonomy			X						
Incentives/Rewards			X						X
Accountability			X						
Trust			X					X	
Organisational learning									
Throughout process	X						X	X	
Post-implementation		X			X				
Inter-project	X								
Benchmarking							X		
Failure analysis						X	X		
Knowledge management					X		X		
IP generation						X	X		
IP acquisition						X	X		
IP protection					X		X		
IP commercialisation						X	X		
Communication									
Intra-firm	X		X		X		X		X
Inter-firm	X				X	X	X	X	X
Gatekeepers	X						X		
Feedback loops	X		X					X	
Appropriate channels					X				

Keys: X – with the contextual elements

All nine models reviewed considered some elements of strategy, while Rothwell and Zegveld (1985) considered factors across five themes. Management and communication factors were considered to some extent by seven models, while organisational learning factors were considered by six models and factors of organisational culture were considered across five models.

The frequency of recurrence of each factor was analysed and the factors that were considered by three or more models were identified and highlighted in bold font in Table 2. Eighteen (18) factors from a total of fifty-six factors were shortlisted based on a frequency of occurrence of three or more. A market-orientation strategy was found to be the most popular consideration among the models appearing with a frequency of eight. A future-oriented strategy, management support for innovation and inter-firm communication were the second highest recurring factors with frequency of six followed by a flexible strategy, management tolerance for risk and intra-firm communication factors with a frequency of five. Inter-functional collaboration, customer-centricity, reduced bureaucracy and enabling technology occurred four times, and all other factors had a frequency of occurrence of three.

6. Conclusion

Nowadays, most developed nations are forging at the frontiers of the 4IR, while many developing countries are trying to catch up with innovation initiatives toward sustainable development. Innovation process models have evolved and continue to change over the industrial era. These models have transformed from generations of simple linear sequential processes to generations of complex iterative parallel processes. A review of nine (9) innovation process models reveals that the innovation process does not occur in isolation but within a broader intra- and inter- organisational context.

Technology was found to be a key area of focus in several models reviewed and continues to be the driving force of innovation in the 4IR. In this vain, technology transfer was considered in one model as a means of levelling the playing field for small firms and less industrially advanced countries. There is a continued focus on customer- and market-orientation considerations. The exponential rate of change that is characteristic of the 4IR requires firms to become increasingly flexible and adaptable to these changes in customer demands and market needs which is aided by data-based 4.0 technologies that are a mainstay of the 4IR. This data-driven environment forces firms to rethink elements of organisational culture drawing on the need for increased change tolerance and enhanced organisational learning. The 4IR also promotes opportunities for innovation beyond the boundary of the firm by operating in a disrupted network where actors across the value chain work simultaneously and independently serving to improve market response rate. This represents another cultural shift for the firm in terms of network operations.

This study focused on the stages and contextual themes governing the innovation process towards emerging industrial revolutions and organisational learning. Several enabling dimensions and elements are discussed. It explored the recurring contextual themes of nine (9) innovation process models advocated in literature, using a comparative analysis. Five contextual themes emerge from the analysis – 1) strategy; 2) management; 3) organisational culture; 4) organisational learning and 5) communication.

Within each theme, several endogenous factors were identified based on the frequency of occurrence of three or more among these models. The most commonly occurring factors, with a frequency of six or more, were found to be: from the strategy domain, customer-centric focus, market orientation and future-orientation; from the management domain, support for innovation and from the communication domain, inter-firm communication.

This study contributes to identify the contextual themes and factors of innovation process models at the firm's level. While each model emphasised specific elements of the innovation process, all elements were found to have relevance in the 4IR with the difference being the mode of application in an increasingly digital environment.

Further studies would explore the innovation imperative with organisational and performance-influencing parameters and develop an innovation process framework in tandem with the considerations of economic growth and the global innovation landscape. Hence, emerging performance indicators, like innovation culture, cluster networks, value and knowledge creation could play a critical role in fostering innovation activities.

Comparative evaluations and case studies are suggested to examine the contextual themes and performance indicators of innovation process towards technology transfer and organisational learning in organisations. Future research could validate the elements identified for large enterprises and small and medium-sized enterprises (SMEs) of varied operations nature, across various industry sectors, separately and collectively in selected nation(s).

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Authors' Biographical Notes:

Ambika Koonj-Beharry *graduated with a BSc. and an MPhil in Industrial Engineering from The University of the West Indies (UWI), St. Augustine, Trinidad and Tobago. She is presently an instructor and pursuing her PhD in Industrial Engineering at the UWI-Department of Mechanical and Manufacturing Engineering. Her research interests are in the fields of knowledge management, cluster development and innovation.*

Kit Fai Pun *is Chair Professor of Industrial Engineering (IE) and the coordinator of IE Research Group at The University of the West Indies (UWI), St Augustine, Trinidad and Tobago. He is Chartered Engineer in the UK, and Registered Professional Engineer in Australia, Europe, Hong Kong, and The Republic of Trinidad and Tobago. Professor Pun is presently the Chair of the Technology and Engineering Management Society Chapter of the IEEE Trinidad and Tobago Section. His research activities include industrial and systems engineering, engineering management, quality management, performance measurement, and innovation systems.*

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