Unveiling Supplier-driven Innovation: Proposing a Buyer-centric Framework

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***Abstract*—In the current competitive landscape, innovation is key to achieving business success. With the constraints of internal resources, businesses are increasingly turning to external collaborations to enhance innovation, especially with their suppliers. This trend has led to the emergence of Supplier-Driven Innovation (SDI), a strategy enabling businesses to supplement their innovation efforts with knowledge and capabilities from suppliers. Despite its significance, there is a notable gap in the literature regarding a theoretical foundation for SDI. This study aims to address this gap by proposing a conceptual framework that advances the understanding of buyer-supplier innovation literature in three key areas: outlining SDI processes from the buyer's perspective, clarifying suppliers' roles in these processes, and exploring the contribution of each identified process to the innovation outcomes. This framework can serve as a guide for practitioners navigating through the complexities of SDI, facilitating its integration into business strategies and enhancing competitiveness in the market landscape.**

***Keywords*—supplier-driven innovation, open innovation, supplier collaboration**

I. Introduction

In recent years, academic scholars and industry practitioners have explored the myriad benefits of innovation. These include sustained value-creation (Amesho *et al.*, 2022; Goldberg & Schiele, 2021), increased productivity (Kogabayev & Maziliauskas, 2017; Musolesi & Huiban, 2010), and superior product performance (Jadhav *et al.*, 2021), all of which contribute to the business's survival and prosperity in an intensely competitive marketplace (Eidizadeh *et al.*, 2017; Jin & Choi, 2019; Kogabayev & Maziliauskas, 2017). However, due to the limitations inherent in relying solely on internal capabilities, businesses increasingly seek to harness external resources to meet their innovation objectives, especially their suppliers (Markovic *et al.*, 2020; Patrucco *et al.*, 2017; Varriale *et al.*, 2022). According to a recent McKinsey survey across 105 leading businesses, the strategic pursuit of supplier innovation contributed to 196% growth of the business.

Supplier-Driven Innovation (SDI) encapsulates the idea that suppliers, with their specialised knowledge and expertise, can introduce novel materials, services, and processes that significantly improve the innovation performance of the buying business (Christensen *et al.*, 2017; Goldberg & Schiele, 2021; Henke Jr & Zhang, 2010). Despite the growing interest in SDI, the model of SDI innovation from the buyer's business perspective remains notably underexplored. The majority of studies have approached the topic from the supplier's perspective (Kim & Chai, 2017; Kurpjuweit *et al.*, 2018; Li *et al.*, 2018; Pulles *et al.*, 2014) or the mutual benefits of collaboration (Li *et al.*, 2021a; Moya *et al.*, 2020; Tirolli & Lemos, 2021; Varriale *et al.*, 2022). While these studies touch upon the buyer business perspective to some degree, they tend to overlook the detailed viewpoints of buyers on what activities are essential for SDI. Additionally, current literature on SDI tends to view the supplier-buyer process as a bundle, necessitating examining the individual process and its relationship with the innovation outcomes (Kähkönen *et al.*, 2017). As the recipient of the values from the supply base, the buyer business plays a significant role in SDI outcomes. For instance, buyers' perceptions and absorptive activities (Li *et al.*, 2021b) primarily affect the extent to which supplier innovation is effectively utilised (Luo *et al.*, 2023). It is essential to redirect research efforts towards directly investigating the business process and innovation outcomes (Kähkönen *et al.*, 2017).

Therefore, this research aims to design an SDI model from the buyer's perspective to answer the following two Research Questions (RQ):

RQ1: What are the main stages of the SDI process from the buyer's viewpoint?

RQ2: How do each of these critical stages influence the innovation outcomes?

By addressing these questions, this research seeks to fill a critical gap in the existing literature and provide businesses with a roadmap to harness the potential of suppliers effectively. In the evolving landscape of business innovation, integrating suppliers into the innovation process has introduced strategic changes. For instance, top

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managers need to adapt to these new processes and rethink how to balance in-house research and external contributions (Ettabaa *et al.*, 2019; Kähkönen *et al.*, 2017). Nevertheless, such transitions are not always seamless. There is a notable disparity between businesses' expectations for supplier innovation and the actual outcomes (International Association for Contract and Commercial Management, 2017). Additionally, it is reported that more than 80% of businesses encounter difficulties incorporating suppliers into their innovation process (Smeets & Graff, 2019). A predominant challenge many businesses face is the absence of a clear and structured process protocol to navigate (International Association for Contract and Commercial Management, 2017). Hence, understanding the SDI process is meaningful in helping businesses understand how innovation happens and trigger better innovation approaches (Garud *et al.*, 2016).

II. Methods

A literature review consolidates existing knowledge, further building this research's theoretical groundings. Scopus is the major database that targets journal articles, conference proceedings, research dissertations, and books. Fig. 1 outlines the four procedures of this research guided by (Durach *et al.*, 2017).

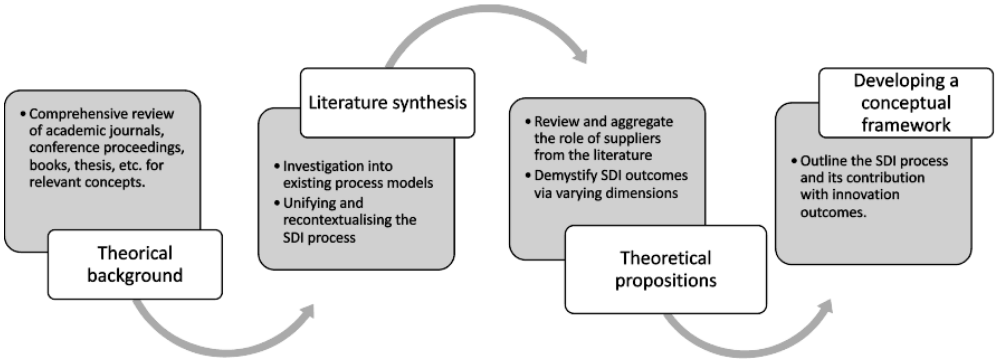

Fig. 1. Four-stage research method.

To design the buyer-centric SDI framework, the research begins by defining the concepts and keyword searching, then filtering and sorting according to the relevance guided by (Durach *et al.*, 2017). Various existing innovation process models are systematically reviewed, compared, and unified to address the underrepresented SDI process model. Then, the unified stages are further contextualised based on the reflection from literature about how each stage of the general innovation process could involve buyer-supplier dynamics. These recontextualised stages answer RQ1, illustrating the essential activities buyers must engage in during the SDI process. Finally, in response to RQ2, propositions are made to address the potential impact of each stage on SDI outcomes. The proposed conceptual framework provides a clear roadmap for businesses keen on leveraging supplier-driven innovation, guiding them towards effectively integrating suppliers into their innovation initiatives.

III. Understanding SDI via Open Innovation

Businesses traditionally followed the closed innovation paradigm, which stems exclusively from internal research and development capabilities (Brem & Tidd, 2012). In 2003, Chesbrough coined the term "open innovation", a paradigm that businesses should employ internal and external knowledge to develop and commercialise their internal innovation. This system is referred to as "open" and can be differentiated from the traditional innovation paradigm because of the permeability of the innovation funnel (Dittrich & Duysters, 2007). In other words, collaborative efforts, including knowledge, skills, resources, and human force exchanged with external partners, have emerged as the new vector of innovation (Kumar *et al.* 2020; Moya *et al.*, 2020). Co-innovating with different actors is the key to open innovation (Fieldsend *et al.*, 2020). These actors encompass suppliers, users, universities, competitors, complementary innovators, and other agents such as regulators (Brem & Tidd, 2012; Fieldsend *et al.*, 2020; Homfeldt *et al.*, 2017). Suppliers are increasingly recognised as pivotal contributors (Goldberg & Schiele, 2021; Patrucco *et al.*, 2017; Tanskanen *et al.*, 2017). As commonly cited in the buyer-supplier innovation literature, suppliers have primary access to their client's needs and mechanisms, thus offering complementary competencies (Luzzini *et al.*, 2015; Patrucco *et al.*, 2017; Rajasekaran *et al.*, 2016). According to a recent study, suppliers can drive up to 65% of business innovation (Kumar *et al.*, 2020). Despite exploring SDI due to its considerable potential, the literature review shows that terminology surrounding SDI is not always consistent across the literature. While some authors use the exact term "supplier-driven innovation" as the primary focus within the buyer-supplier innovation context (Christensen *et al.*, 2017; Henke Jr & Zhang, 2010), others employ variations such as "supplier innovation", "supplier-enabled innovation", or "supplier integration (on innovation)". At the core, all these terminologies acknowledge suppliers' importance in the innovation ecosystem. However, these terminologies can be slightly different in context, level of supplier contribution, and nature of involvement in the innovation process. For instance, supplier innovativeness emphasises the supplier's inherent capability to introduce innovation to the buyer business (Bryan Jean *et al.*, 2017; Kim & Chai,

2017; Li *et al.*, 2018). Supplier innovation is a broad term that refers to suppliers' capabilities and outcomes driven by suppliers (Luo *et al.*, 2023; Moya *et al.*, 2020). The interchangeable use of SDI with other terms is observed from the literature (Jean *et al.*, 2017; Henke Jr & Zhang, 2010; Li-Ying *et al.*, 2021), possibly due to the overlapping nature of the concepts they represent.

IV. Identifying SDI Process

To develop the buyer-centric SDI model, existing models are reviewed, analysed, and unified as follows:

A. Antecedents (Before 2000)

Table I presents the summary of some early investigations into innovation processes. By adopting fifth-generation innovation models (Rosell & Lakemond, 2012), these early models are described as "project-oriented" models based on "technology-push" or "demand-pull" (Naoui-Outini & El Hilali, 2019). As evident in Table I, the early innovation process models are primarily linear and divide the innovation process into several sequential steps. The other early innovation model type is the stage-gate model. Here, the innovation process is divided into several stages and only goes to the next stage after passing the "gate". This "Gate" represents the evaluation point where the process is carefully assessed before continuing (Grönlund *et al.*, 2010). The stage-gate model is extensively used for the product innovation process that allows the streamlining of disordered innovation activities through parallel stages (Grönlund *et al.*, 2010). These models provide an early view of how innovation occurs within the business, with many similarities from idea generation to commercialisation. One reason could be that early models still focused on closed innovation, in which case generating ideas within the business is always the starting point.

TABLE I. Early Innovation Process Models

Authors	Model types	Key activities
Lynn *et al.* (1996)	Linear model	Idea generation Idea screening Innovation development Testing New product launch
Kumar *et al.* (1996)	Linear model	Initial projection Commercial evaluation Development Manufacturing launch Initial commercialisation
Chiesa *et al.* (1996)	Linear model	New concepts generation Product development Process innovation
Cooper (1994)	Stage-gate model	Idea screening Preliminary investigation Build business case Development Test and validate

B. Open Innovation Process Models (2000–2010)

Examples of open innovation process models are shown in Table II. These open innovation process models have more diverse model types than the previous process models.

TABLE II. Open Innovation Process Models

Authors	Model types	Key activities
Gassmann and Enkel (2004)	Linear model	Scanning of new technologies evaluation of prospective technologies Prototype development Product commercialization
Docherty (2006)	Funnel model	Fuzzy front-end Development commercialisation
Fetterhoff and Voelkel (2006)	Funnel model	New concepts generation Product development Process innovation
Grönlund *et al.* (2010)	Stage-gate model	Several stages and condition-go decision-making during the definition, design, and validation.
Amaral and Rozenfeld (2007)	Stage-gate model with macro and micro phases	Understand the motivation Analyse the situation Define the changing products Implement (plan, design, execute, release)
Hansen and Birkinshaw (2007)	Stage-gate model	Idea generation Conversion Diffusion

Noticeably, open innovation process models represent a significant evolution from the older ones as they address seeking and embracing external resources. For instance, the focus of the initiation phase has shifted from internal brainstorming to a broader scope that includes scanning and searching externally. Additionally, the stage-gate model demonstrates the increased popularity in the context of open innovation. One possible explanation is that the "gate" in the stage-gate model can act as the selection mechanism for external resources that fit well with the open innovation context. For instance, the previous process model is reviewed by incorporating both macro and micro phases, highlighting the external collaboration and translation of knowledge into product specification (Amaral & Rozenfeld, 2007). In addition, the funnel model (Cano-Kollmann *et al.*, 2016; Chiesa *et al.*, 1996), as a novel model introduced in the era of open innovation, highlights the selectivity of external ideas when the inputs expand. As discussed previously, the main difference between the closed and open innovation models is the permeability of the innovation funnel (Dittrich & Duysters, 2007), which means that external ideas can penetrate the business boundary. The funnel model demonstrates its competency in developing the open innovation model because it includes improving the innovation capability through the integration of outside partners. This open innovation model promotes innovation diffusion and connectivity (Cano-Kollmann *et al.*, 2016), whereas early innovation models prioritise the selling of products. This idea is evident in the stage-gate model (Hansen & Birkinshaw, 2007) proposed in 2007, which uses "diffusion" as the ending stage. Although their defined steps involve traditional activities like idea generation and conversion, they incorporate in-house operation and inter-business collaboration. For instance, the idea generation stage is divided into in-house creation and external

collaboration, and the conversion stage includes the selection of outside ideas.

C. Recent Open Innovation Process Models (After 2010)

Table III presents a selection of recent innovation process models, demonstrating the growing trend of tailoring the general open innovation process to fit specific industry contexts better. As can be observed, these models often integrate industry-specific elements into the identified innovation activities to achieve alignment with particular sectors. For instance, in the software sector, the recent model incorporates the "monitoring of external environment", which, based on their specification, refers to the search data sources for identifying market innovation (Eito-Brun & Sicilia, 2017). This stage shows some inconsistency with other models, where the activity of studying market potential is located in the early stages. A possible explanation is that moving the market potential to a later stage is preferable in the software development sector when there are rapid changes in the industrial environment. The products regarded as the best-advanced innovation in the first stage may not be the best-advanced innovation in the later stage. Technological feasibility could be another explanation. Since software development entails end-user feedback for later updates, continuous monitoring of user feedback is important to refine the functionality of software products. These recent process models are specific to the exact industry, which calls for a process model that can be applied to the generic context (Varriale *et al.*, 2022).

TABLE III. RECENT OPEN INNOVATION PROCESS MODELS

Authors	Model types	Context
Sigismund *et al.* (2013)	Generation of ideas Selection and conceptualisation Technical development Market launch	Transmission and service industry
Tidd and Bessant (2020), cited by Abhari *et al.* (2020)	Search internal/external for ideas Select/decide the best idea. Launch the new product/service Repetitive learning and improvement	Social product development
Jenatabadi (2014)	Introducing innovation Adopting innovation diffusing innovation	Food industry
Homfeldt *et al.* (2017)	Idea development Predevelopment Early product emergence	Automotive industry
Tidd and Bessant (2020)	fication of innovation opportunities ssment of innovation opportunities itoring of the external environment Exploitation of innovation	Software development industry
Abhari *et al.* (2020)	Searching new ideas Selecting promising ideas Implementation of new ideas as products Learning within the social product development community	Social product development

In line with this gap, the proposed conceptual framework in this research is not confined to specific industries. Instead, it seeks to enhance its practical relevance by providing applicability and generalisability across diverse sectors.

Upon reviewing various innovation process models, it is observed that multiple innovation process models reveal the overlap in key processes. Recent process models appear to focus on dissecting/grouping similar processes, rephrasing the terminologies used (e.g., equating "idea development" with "idea generation"), or contextualising them to align with specific industries drawn from other models (e.g., evolving from "learning externally" into "learning from the social product development community"). As a result, this research consolidates the generic open innovation process from earlier literature into five key stages: preparing, searching, selection, integration, and improvement.

While the general processes can be used to explain SDI, they fail to capture the contextualised descriptions within this context sufficiently. Hence, this research proposes the following stages as recontextualised innovation processes for SDI: Identify the innovation need, scout innovation opportunities from the supplier market, assess and select innovative suppliers, integrate supplier inputs to the business innovation, and supplier development. This revised SDI process differentiates from the existing innovation process model by considering the specific supplier-buyer dynamics and outlining the activities the buyer business performs that could lead to enhanced innovation.

V. PROPOSING A BUYER-CENTRIC SDI CONCEPTUAL FRAMEWORK

A conceptual framework is shown in Fig. 2 for SDI is proposed based on the previously identified processes. It has three major components: the SDI process, the SDI outcomes, and propositions on the contribution of individual processes to the innovation outcomes. They are explained as follows:

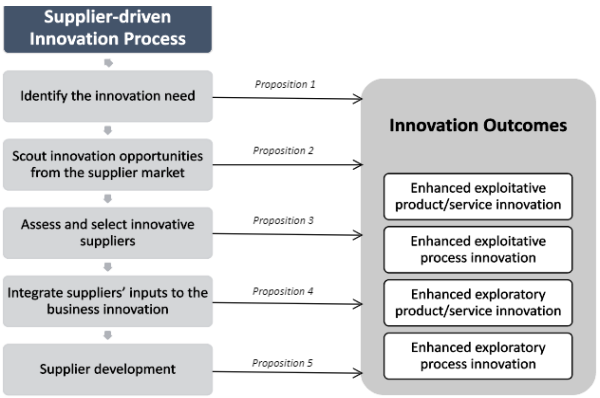

Fig. 2. Proposed buyer-centric SDI conceptual model.

A. SDI Outcomes

The first dimension is relevant to the innovation intensity, which is based on whether the outcome signifies a groundbreaking novelty (radical) or minor changes to existing components (incremental) (Rosell & Lakemond, 2012; Varriale *et al.*, 2022). Most leading businesses carry radical and incremental innovation, coined as "explorative innovation" and "exploratory innovation" (Li *et al.*, 2021a). Explorative innovation is those small, macro, incremental improvements made to existing products/services and processes, while exploratory innovation is the large-scale development of disruptively new products/services and processes (Li *et al.*, 2021). Explorative innovation is often synonymous with

incremental innovation, and exploratory innovation is often used interchangeably with radical innovation (Li *et al.*, 2021). However, the terms explorative and exploratory innovation are used more in the open innovation context, as they address alignment with the external environment for new or improved products, services, and processes (Enkel *et al.*, 2017; Li *et al.*, 2021). Empirical findings from the recent study corroborate the similar behaviour of buyer businesses in reaction to explorative and exploratory innovation, and the process involved in the buy-side of collaborative innovation is independent of the innovation intensity (Varriale *et al.*, 2022). This is observed as managers in the buyer business display an equal interest in both radical and incremental innovations among their suppliers (Varriale *et al.*, 2022).

TABLE IV. SUMMARISING THE PROPOSED SDI OUTCOMES

Enhanced Innovation outcomes	Details	Authors
Radical product innovation	Internal superior resources; propose new product design; knowledge and expertise in new materials; suggestions on new product design; development of new technologies relevant to the end product; exclusive access to the latest material; trademark applications; Industrial designs; creative goods and services; open new markets applications; stimulate creativity for new product.	Dutta *et al.* (2019); Henke Jr and Zhang (2010); Li *et al.* (2021b); Patrucco *et al.* (2017); Varriale *et al.* (2022)
Incremental product innovation	Development of innovative components; updates of new features on existing products; suggestions on product improvement; development of component technologies for multiple end products; improvement of product quality and performance; extend functionality scope.	Klioutch and Leker (2011); Li *et al.* (2021a); Li *et al.* (2021b); Patrucco *et al.* (2017); Smeets and Graff (2019)
Radical process innovation	Develop new internal processes; develop new processes at the supplier interface; access to the advanced process technologies; customised resources.	Durach *et al.* (2017); Limbach (2013); Naoui-Outini and El Hilali (2019); Rosell and Lakemond (2012); Wagner and Bode (2014)
Incremental process innovation	Improve the current production process on behalf of buyers; provide a better supply of machinery for streamlining the existing process.	Limbach (2013); Wagner and Bode (2014)

The second dimension is relevant to the innovation typology, differentiating the innovation between product/service and process innovation. It is crucial to distinguish whether the innovation efforts are towards the product/service or the process, which is widely accepted in supply chain and innovation management literature (Wagner & Bode, 2014). Process innovation is described as implementing new or improved procedures, methods, or technology, while product/service innovation is defined as offering new or improved products/services (Wagner & Bode, 2014). Although some studies (e.g., Moya *et al.*, 2020) measure innovation outcomes based on the rate of new products/services, process innovation plays a significant role in business innovation. For instance, it can positively impact product innovation, especially radical product innovation (Lee *et al.*, 2019). Table IV summarises the findings from the reviewed literature. It identifies and consolidates the potential contributions of suppliers to business innovation from four different perspectives: exploitative product/service innovation, exploitative process innovation, exploratory product/service innovation, and exploratory process innovation.

B. Propositions of SDI Process and Outcomes

Scholars have identified the importance of early identification of innovation needs and goals (Eito-Brun & Sicilia, 2017; Henke Jr & Zhang, 2010; Luzzini *et al.*, 2015; Patrucco *et al.*, 2017). Suggestions and expected goals from different business units will be collected, and suppliers, as the primary source of innovation, can be engaged in this identification phase (Abhari *et al.*, 2020; Ettabaa *et al.*, 2019). Some authors use the term "innovation strategy", which can be defined as an explicit roadmap for a desired future in accordance with the supply (Luzzini *et al.*, 2015; Moya *et al.*, 2020). The reconciled and aligned goal orientation can increase suppliers' awareness about requirements from the buyer's side, thus contributing better technical expertise and compacity during the innovation (Goldberg & Schiele, 2021). Thus, the following proposition is posited:

Proposition 1. Identifying clear and shared innovation goals with suppliers can contribute to enhanced exploitative product/service innovation, exploitative process innovation, exploratory product/service innovation, or exploratory process innovation.

The second stage in the SDI process is scouting supplier opportunities based on the business needs aligned with the previous step. These scouting activities can include innovation days and scouting trips (Homfeldt *et al.*, 2017; Legenvre & Gualandris, 2018; Nougu ès *et al.*, 2017) when the business team can pay a visit to potential suppliers in specific regions (Nougu ès *et al.*, 2017) and attend the innovation pitch presented by suppliers about their winning ideas and their commitment to investment (Legenvre & Gualandris, 2018; Nougu ès *et al.*, 2017). During the scouting process, businesses should focus on the suppliers' capabilities for innovation besides quality, lead time, and flexibility (Legenvre & Gualandris, 2018). The scouting supplier stage helps the SDI process because businesses can leverage the supply network and explore more comprehensive collaboration with suppliers to initiate their opportunity for better innovation (Homfeldt *et al.*, 2017; Kar & Pani, 2014). Also, it enables a better understanding of suppliers' processes, capabilities, and restrictions, allowing for better planning, forecasting, product and process design, and transaction management within the business (Patrucco *et al.*, 2017). Hence, the following proposition is suggested:

Proposition 2. Scouting innovation opportunities from the supplier market can contribute to enhanced exploitative product/service innovation, exploitative

process innovation, exploratory product/service innovation, or exploratory process innovation.

The next stage in the SDI process is assessing and selecting innovative suppliers based on the input of the shortlist of potential suppliers from the previous stage. The business can evaluate the suppliers who can contribute to the business innovation and select them as strategic partners to work on it jointly. The selection and evaluation of suppliers are critical since they are directly related to the business's success in adopting innovation practices if the selected partnership can reflect the buyer's need (Gupta & Barua, 2017). In this stage, businesses examine and measure the performance of a number of suppliers on numerous selection criteria, such as price, lead time, and financial stability, and then prioritise these requirements by assigning a weighted average for each (Kar & Pani, 2014). While supplier selection criteria vary depending on the scenario, business decision-makers should adopt the proper selection criteria according to real business cases (Markovic *et al.*, 2020; Naoui-Outini & El Hilali, 2019). The following proposition is made to indicate the positive relationship between the selection of innovative suppliers and innovation outcomes:

Proposition 3. Selecting innovative suppliers can contribute to enhanced exploitative product/service innovation, exploitative process innovation, exploratory product/service innovation, or exploratory process innovation.

Then, the buyer business integrates innovative suppliers' expertise selected from the previous step to the final leveraging of innovative suppliers on the innovation performance of the businesses (Bengtsson *et al.*, 2013). The value of SDI is mainly achieved by capturing the supplier's inputs. From the innovation perspective, integration should be perceived as the merging of complementary knowledge and resources required for innovation rather than being viewed as the sharing of knowledge (Bengtsson *et al.*, 2013). From a strategic perspective, the degree to which buyers and suppliers are aligned is strongly tied to the success of the innovation activity (Patrucco *et al.*, 2017). The literature also asserts that during the integration, the crucial task will be transforming the supplier inputs into the "interchangeable" knowledge asset that is capable of being used and applied in a broader range of business functions, referring to the "standardization" and "backward compatibility" (Homfeldt *et al.*, 2017). The following proposition is put forth:

Proposition 4. Integrating suppliers' inputs to the innovation can contribute to enhanced exploitative product/service innovation, exploitative process innovation, exploratory product/service innovation, or exploratory process innovation.

Finally, some authors indicate the importance of joint evaluation by illuminating the active role of the buyer business in supplier development (Li *et al.*, 2021b; Tirolli & Lemos, 2021). The concept of the stimulation of supplier innovation is introduced, referring to the buyer's actions to enhance its supplier's innovativeness (Pihlajamaa *et al.*, 2019). It is consistent with the idea of supplier development, which refers to the buyer's efforts to improve its supplier's performance so that they can receive better products or services in return. Rational suppliers contribute their efforts to the buying organisations only if they believe it will benefit them in the future (Wagner & Bode, 2014). It is suggested that the buyer business can enhance the likelihood of accessing suppliers' innovative ideas by demonstrating their commitment to good practices, openness and transparency (Pulles *et al.*, 2014; Rajasekaran *et al.*, 2016). In light of the above, the following proposition is inferred:

Proposition 5. Supplier development can contribute to enhanced exploitative product/service innovation, exploitative process innovation, exploratory product/service innovation, or exploratory process innovation.

This presented conceptual framework offers guidance for practitioners navigating the complexities of SDI. The outlined stages assist businesses eager to leverage the potential of supplier innovation, prompting both strategic and operational adjustment for optimised outcomes. The correlation between stages and proposed outcomes can enrich businesses' understanding of SDI when integrating SDI into their overarching business strategy, ultimately leading to enhanced competitiveness in today's dynamic market landscape.

VI. Conclusions and Future Directions

As suppliers' role in business innovation increases, understanding SDI from the buyer business perspective is significant. This research presents a conceptual model outlining five key processes: identify innovation needs, scout supplier market for innovation opportunities, assess and select innovative suppliers, integrate supplier inputs, and supplier development. It proposes that these processes can enhance exploitative and exploratory innovation regarding products/services and processes. This model is developed through a comprehensive literature review and opens up new theoretical and empirical exploration.

Several limitations in this paper are acknowledged for follow-up research. There is a need for empirical evidence to support the theoretical propositions. Future research would benefit from collecting and analysing empirical data to validate the propositions and refine the conceptual framework. Moreover, the current study does not consider the role of contextual factors like supplier diversity and intellectual property laws in the SDI process. Future research should investigate how different variables can impact the stages of the SDI process. Additionally, there should be a clear focus on understanding how Industry 4.0 technologies, such as artificial intelligence, specifically contribute to the SDI. Addressing these areas will significantly improve the practicability of the SDI model for academic and industry applications.

Conflict of Interest

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Yuting Sun wrote the paper and conducted the research; Stephen Cahoon, Peggy Chen, and Hadi R. Vandchali provided supervision, discussed the structure and content, and reviewed drafts of the manuscript; all authors had approved the final version.

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