

# The Impact of Supplier Involvement in Product Development on Supply Chain Risks and Supply Chain Resilience

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## ABSTRACT

Nowadays, the aspects of managing risks and building resilience are crucial for maintaining the continuity of business processes. Therefore, it is highly valuable to recognize those aspects that support such activities. The main purpose of this article is to investigate whether supplier involvement in product development (SIPD) affects the degree of supply chain risk and thus, indirectly impacts supply chain resilience. The study is based on a survey conducted among 500 manufacturing companies, from which several hypotheses have been defined and tested. This allowed the verification of a theoretical model covering the following three research areas: supplier involvement in product development, supply chain risks and supply chain resilience. In particular, the study confirmed that implementation of partnership practices during SIPD positively influences supply risk reduction, while extensive communication during SIPD minimizes operational risk for a company, i.e. risk of human failures and inadequate or failed internal processes. Subsequently, the positive impact of reduced operational risk on SCRES has also been confirmed.

**Keywords:** *supplier involvement, product development, supply risk, operational risk, supply chain resilience*

## 1. INTRODUCTION

Although supplier involvement in product development (SIPD) has long been a subject of publications, there are still few quantitative studies linking this issue with supply chain resilience and risk management. The importance of product development activities for designing supply chains that are less vulnerable to disruptions is well illustrated in the case study on Boeing. Tang *et al.* (2009) highlighted that supply chain risks should have been managed as early as the design stage of the 787 Dreamliner. In turn, Melnyk *et al.* (2014), based on Boeing's experiences, pointed out that supply chain resilience is already determined at the stage of the product development process.

The impact of product complexity and diversity on supply chain configuration is well researched (Ülkü and Schmidt, 2011; Khan, *et al.*, 2012; Pashaei and Olhager, 2015). The fundamental considerations are the commonly known determinants influencing the choice of lean or agile strategies. These factors are primarily product characteristics, e.g. degree of innovativeness, demand, or production environment type (Jones, *et al.*, 2000; Christopher, 2006; Drake, *et al.*, 2013).

The new product development (NPD) process "is a series of interdependent and often overlapping stages during which a new product (or process or service) is brought from

the "idea" stage to readiness for full-scale production or service delivery" (Handfield *et al.*, 1999). Over the years, many concepts have emerged that combine product development with supply chain processes and structures, all of which are based on supply chain collaboration. The subjects of research are mainly design for assembly (Boothroyd, 1994), design for manufacturability (O'Driscoll, 2002; Lu and Wood, 2006) and design for supply chain management (Wilbers, 2015, p. 296). However, due to interest in environmental protection, many publications on design for environment (Sroufe, *et al.* 2000; Fiksel, 2009) and design for sustainability (Rocchi, 2005; Ceschin and Gaziulusoy, 2016) have appeared recently. Competing against time is a key for innovation success (Stalk and Hout, 1990). Therefore, the risks should already be considered at the stage of new product development. Khan *et al.* (2008) provided a framework for design-led risk management. The authors explained that joint product development is an opportunity for effective supply chain risk mitigation.

Supply chain risk mitigation is enabled by partnership and trust (Nishat Faisal, *et al.*, 2006). The definition of supplier involvement also underlines the necessity of close cooperation in the supply chain (Wagner, 2012). Petersen *et al.* (2005) define early supplier involvement (ESI) as an "important coordinating mechanism for decisions that link product design, process design, and supply chain design together". Because the supplier is the most often included supply chain link in the development of product innovations (Ocicka, 2017), cooperation with this partner may have a key impact on the efficiency and effectiveness of supply chain processes. Indeed, past studies have confirmed the positive impact of supplier involvement on new product development performance (Petersen, *et al.*, 2003; Parker, *et al.*, 2008), new product performance (Li, *et al.*, 2010; Wagner, 2010), financial and operational performance of the company (Petersen, *et al.*, 2005; Feng, *et al.*, 2013) as well as supplier's operational performance (Carr, 2008).

Achieving both the operational and strategic goals of supply chain processes is hampered by a variety of risks (FERMA 2003; COSO 2004, p. 25; ISO 31000:2018). In the face of the high environmental and business uncertainty of the twenty-first century (shortening product cycles, competing against time, an increasing number of serious supply chain disruptions and the growing role of adaptation, flexibility and resilience), examining the role of SIPD in supply chain risk management seems to be the next significant research direction. There are publications

highlighting the interest in the dependence between risk and involving suppliers in the product. This comes from conducted qualitative research based on observations or interviews development (Khan, *et al.*, 2008; Tang, *et al.*, 2009). Therefore, the subsequent step should be to statistically validate whether SIPD impacts risk in the supply chain, and if so, which SIPD practices impact which types of risk. This article makes an attempt to fill this gap by aiming to investigate whether SIPD affects supply chain risks and thus, indirectly impacts supply chain resilience.

Building resilient supply chains incorporates various drives not only to respond to problems but also to anticipate them in order to reduce the risk of adverse events before they occur (Hohenstein, *et al.*, 2015; Tukamuhabwa, *et al.*, 2015; Ali, *et al.*, 2017). The results of this research provide companies with reliable knowledge on how to carry out SI so that the designed supply chain for a new product will be characterized by greater efficiency of the processes implemented in supplier-customer cooperation. The basic classification divides supply chain risk into supply risk, operational risk and demand risk (Johnson, 2001; Zsidisin, 2002; Manuj and Mentzer, 2008). Because SIPD concerns itself the relationship between an enterprise and its suppliers, the presented quantitative study focuses on exploring two types of risk: the operational risk of the enterprise and the supply risk.

The manuscript makes three specific contributions to the literature. First, it develops the theoretical model on SIPD, risk and resilience. For this purpose, an in-depth literature review in various thematic areas was conducted. Then, the proposed model was verified with the use of several statistical methods, with empirical data being gathered from 500 surveyed manufacturing companies. Finally, based on the observations, several conclusions were reached that contribute to the theory and practice.

This article is structured as follows. Section 2 organizes past studies in the three main investigated areas - which are supplier involvement in product development, supply chain risk and supply chain resilience. The next two sections develop a theoretical model and explain the methodology utilized to perform a quantitative research. The research results are presented in part 5, whereas discussion on findings is conducted in part 7. The final section of the paper provides conclusions and implications.

## 2. LITERATURE REVIEW

### 2.1 Supplier Involvement in Product Development

The issue of supplier involvement in product development has been a subject of research for many decades. Initially, articles focused mainly on concurrent engineering (Winner, 1988, pp. 11-13). Then, the supplier became perceived as an important partner, regardless of the stage of the product development process (Handfield, *et al.*, 1999). Birou and Fawcett (1994) explained that SIPD concerns 'supplier participation in the integrated product development process'. Melander (2014) underline the importance of collaborative new product development that are based on the balance of power between company and supplier. Over time, it has been observed that involving suppliers from the very beginning of NPD, e.g. at the stage of generating and selecting ideas, can be a source of

significant benefits in terms of costs, time and quality (Petersen, *et al.*, 2005; Handfield and Lawson, 2007; Wagner, 2012). This observation allowed the creation of the early supplier involvement concept (ESI) (Bozdogan, *et al.*, 1998; Dowlatshahi, 1998; Wagner, 2012). Subsequent publications indicated a growing interest in the issue of integrating suppliers in product development and, at the same time, designing manufacturing systems together with business partners (McIvor and Humphreys, 2004; Lyu and Chang, 2007) or even 'off the shelf' processes (Cagli, *et al.*, 2012). Eventually, authors recognized that supplier involvement unites product design, process design and supply chain design (Petersen, *et al.*, 2005).

The latest definition of SIPD states that it is 'a process of managing the involvement of suppliers in the development of (new) products/services/processes/technologies for the chosen category' (Luzzini, *et al.* 2015). Thus, the SIPD concept extends to the aspect of process design and configuration of new supply chains. There are authors who strongly emphasize the simultaneity and connection of product development processes with supplier management and product management (Wynstra, *et al.*, 2001). Interestingly, Dowlatshahi (1998) distinguished four areas that form the ESI structure: design, procurement, suppliers, and manufacturing. Jiao, *et al.* (2008) enriched this framework with the stages of manufacturing process design.

### 2.2 Supply Chain Risks

In the international standards, risk management (RM) is described as a specific process which consists of several steps including risk assessment, risk treatment (e.g. reduction, avoidance, transfer), risk control and risk monitoring (e.g. FERMA 2003; COSO 2004, p. 25; ISO 31000:2018). The first stage of RM is the identification of threats and potential adverse events that may disturb operations carried out under normal conditions. These are usually specific to individual businesses and processes. Risk management has become the topic for many publications. The authors dealt, among others, with risk analysis (Jüttner, 2005) as well as risk mitigation methods and strategies (Jüttner, *et al.*, 2003; Rice and Caniato, 2003; Chopra and Sodhi, 2004).

In recent years, Enterprise Risk Management (ERM) has evolved into the concept of supply chain risk management (SCRM). SCRM is a continuous long-term process involving supply chain links, in which participants actively communicate in order to develop appropriate management strategies (Zsidisin, *et al.*, 2000). The primary goal of this concept is to ensure a smooth and uninterrupted flow of materials from the initial supplier to the consumer (Waters, 2007, p. 86).

For the last two decades, supply chain risk has been analysed from different perspectives. Johnson (2001) studied two main risk sources. The first is related to demand changes, while the second is associated with supply problems resulting from disruptions and capacity limitations. Manuj and Mentzer (2008) recognized three main types of risks, which are: demand risk, supply risk and operational risk. Pfohl, *et al.* (2011) expanded this with new categories, which are external risk, process risk and control risk. There

are also authors that followed significantly different supply chain risk classification (Wang and Abareshi, 2014).

Demand risk is mainly related with an uncertainty resulting from the seasonality or volatility of clients' orders (Johnson, 2001). Supply risk can be defined as 'the potential occurrence of an incident associated with inbound supply from individual supplier failures or the supply market, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety' (Zsidisin, 2002). Zsidisin (2003) listed nineteen different characteristics of supply risk. These are related, among others, to supplier quality, time and flexibility performance.

According to the Directive 2009/138/EC, operational risk is 'the risk of a change in value caused by the fact that actual losses, incurred for inadequate or failed internal processes, people and systems, or from external events (including legal risk), differ from the expected losses'. Operational adverse events can lead to a crisis situation not only in the buyer's company, but also in the supplier's company, resulting in problems with supply quality and punctuality. History is a source of examples of such situations (Norrman and Jansson, 2004). Incidents can seriously disturb supply chain processes causing a domino effect (Wieteska, 2018c) and bring social, environmental, financial or reputational losses (Wieteska, 2018a). There are specific factors that can increase the risk in supply chains, such as dependences in supplier-buyer relationships (Svensson, 2004; Hallikas, *et al.*, 2005).

### **2.3 Risk Related Aspects in Past Research on SIPD**

Scientific publications on SIPD designate several areas of research in which there are some threads related to the generally understood notion of risk. In the first area, researchers are interested in issues that allow the characterization of the conditions for SIPD implementation. They focused on identifying the benefits, drivers, enablers, or barriers to integrating suppliers in the product development process. The assessment of risk is carried out mainly in the context of SIPD benefits and problems. Among the most frequently mentioned advantages of SIPD are improvement of product quality, reduction of costs as well as duration of the project (Ragatz, *et al.*, 1997; Wynstra and Ten Pierick, 2000; Eisto, *et al.*, 2010). Littler, *et al.* (1995) distinguished reducing the cost and risk of product R&D as one of the reasons for collaboration. Further, among the main SIPD objectives, Handfield, *et al.* (1999) recognized: reducing technological risk and reducing financial risk. In turn, Mikkola and Skjoett-Larsen (2003) pointed out the risk of losing proprietary knowledge as one of the disadvantages of SIPD.

For many authors, another area of SIPD research is the supplier-customer relationship in the NPD process (Wasti and Liker, 1997; Carr, *et al.*, 2008; Kähkönen, *et al.*, 2015). Attention is paid here to, among others, considerations regarding supplier dependence (e.g. LaBahn and Krapfel, 1994; Carr, *et al.*, 2008) and buyer dependence in joint product development (e.g. Kähkönen, *et al.*, 2015). Interestingly, Asmus and Griffin (1993) indicate that avoiding double/multi sourcing is justified when implementing ESI, whereas Tang (1999) argues that this may

increase supply risk because of the reduced bargaining power of the company. Next, many studies concern supplier-customer communication in NPD (Hoegl and Wagner, 2005; Tavani, *et al.*, 2013). Scientists highlight the number of separate departments that are involved in product development activities (Maffin and Braiden, 2001; McIvor and Humphreys, 2004) as well as the necessary abilities and skills of the engaged employees (Birou and Fawcett, 1994; Ye, *et al.*, 2018). In the area of supplier-customer relationship, the issue of risk appeared only in the context of supplier-customer homophily as well as business contracts that regulate supply chain cooperation. Wagner (2010) considered similarity between client and supplier in risk taking to be significant for the effectiveness of the NPD process. In turn, the practice of risk and reward sharing was highlighted as an important factor in SIPD success in other works (McGinnis and Vallopra, 1999; Johnsen, 2009).

The third area of research on SIPD concerns managing suppliers involved in product development. It covers the issue of supplier selection (McGinnis and Vallopra, 1999; Petersen, *et al.*, 2005; Wagner and Hoegl, 2006), supplier assessment criteria, including supplier capabilities (Wasti and Liker, 1997; LaBahn and Krapfel, 2000), supplier segmentation (Handfield, *et al.*, 1999; Wynstra and Ten Pierick, 2000) and supplier development practice (Fun, *et al.*, 2000). Initial and periodic assessment is shown to support supplier risk management (Kara, *et al.*, 2018). Further, supplier development programs are aimed at improving those areas in which suppliers need improvement (Krause, *et al.*, 1998). Interestingly, Handfield, *et al.* (1999) used supplier risk assessment as a tool to select the right supplier to be integrated in an NPD project. They also considered supplier development as a way to reduce various supply risks should a partner not meet the requirements for integration.

The last main research field links supplier involvement with NPD success. It is related to the three previous areas because researchers often studied the impact of the previously mentioned variables on product development. Many factors are recognized that positively affect NPD. In general, closer supplier-customer cooperation determines higher NPD project performance (Parker, *et al.*, 2008). Selecting the right supplier using a detailed assessment improves product design (Petersen, *et al.*, 2005) and is an opportunity for supply chain risk reduction (Tang, *et al.*, 2009). Wagner (2010) underlines the positive impact of supplier-customer homophily on project costs and speed as well as product innovativeness. Further, to get the highest quality and cost and time outcomes, companies should involve suppliers in the early stages of the NPD process (Eisto, *et al.*, 2010; Wagner, 2012). Chien and Chen (2010) indicated that cross-functional integration has a positive effect on the NPD process. Similarly, technology and cost information sharing promotes better NPD project outcomes (Petersen, *et al.*, 2003). Tavani, *et al.* (2013) observed that a company's absorptive capacity is has an impact on the financial and nonfinancial performance of new products. Researchers also confirmed that product modularity has a direct and positive effect on NPD time (Danese and Filippini, 2010) and significantly improves NPD outcomes (Ye, *et al.*, 2018). Better manufacturability is one of the benefits of ESI (Mikkola and Skjoett-Larsen, 2003). Interestingly, Khan, Christopher and Burnes (2008) considered the linking of product design, supply chain operational performance and

risk management. They provided a case that the design process is a platform to supply chain risk management and the involvement of suppliers in it is key to reducing risk. Finally, following previous qualitative research, Tang and Musa (2011) listed early supplier involvement as the one of the qualitative solutions to product and process design risk, production capacity risk, operational disruption as well as risk, whose source can be supply capacity.

### 2.4 Supply Chain Resilience

According to the Cooper, Lambert and Pagh (1997) ‘supply chain management is the integration of business processes from end user through original suppliers that provides products, services and information that add value for customers. Melnyk *et al.* (2014) stated that ‘resilience is the heart of current supply chain management thinking’. Ponis and Koronis (2012) described supply chain resilience as ‘the ability to proactively plan and design a supply chain network for anticipating unexpected disruptive (negative) events, respond adaptively to disruptions while maintaining control over structure and function and transcending to a post event robust state of operations, if possible, more favorable than the one prior to the event, thus gaining competitive advantage’. This leads to the conclusion that the design of new products and supply chains should primarily take into account its resilience aspect.

Supply chain resilience (SCRES) connects supply chain risk management with business continuity management theory. The latest definition of SCRES, developed by Datta (2017), confirms this tendency: ‘supply chain resilience is a dynamic process of steering the actions so that the organization always stays out of danger zone, and if the disruptive/uncertain event occurs, resilience implies initiating a very rapid and efficient response to minimize the consequences and maintaining or regaining a dynamically stable state, which allows it to adapt operations to the requirements of the changed environment before the

competitors and succeed in the long run’. The SCRES concept is based on its time aspect. Thus, its frameworks are expressed with the use of several disruption phases, e.g.:

- ‘before’, ‘during’ and ‘after’ the crisis situation (Ali, *et al.*, 2017) or
- readiness, response, recovery and growth (Hohenstein, *et al.*, 2015) as well as
- proactive and reactive strategies (Tukamuhabwa, *et al.*, 2015).

Cascade constructions of the SCRES framework may also include a number of abilities (Ponomarov and Holcomb, 2009). A systematic literature review showed that the main SCRES elements (enablers, practices) are flexibility (the most common attribute), redundancy, transparency and visibility, agility, collaboration, and information sharing (Wieteska, 2018b).

The structure of resilient supply chain involves partners located in resilient cities, which are free from natural disasters and/or prepared for climate changes. This is especially important for single sourcing strategy, that accompanies SIPD most often. Thus, SCRES hugely depends on the adaptive actions performed by governments (Wieteska-Rosiak, 2020). Furthermore, the 2019–20 coronavirus pandemic showed that in the event of extreme events, the legal and financial instruments are also crucial to ensure business continuity and recovery.

## 3. THEORITICAL MODEL AND HYPOTHESES DEVELOPMENT

Based on the literature covering both quantitative and qualitative studies, a theoretical model (Figure 1) is proposed to evaluate the relations between supplier involvement, two types of supply chain risks and supply chain resilience. Individual relations are expressed in the form of hypotheses, the justification for which is presented in the following considerations.



Figure 1 Theoretical model

### 3.1 Relation Between Supplier Involvement in Product Development and Company's Operational Risk

The impact of product design on supply chain configuration is undisputed (Khan, *et al.*, 2012). A product's architecture determines the supply chain network and its processes (Ming-Chuan and Okudan, 2014). Moreover, process design and supply chain design are regarded as important stages of the NPD process (Petersen, *et al.*, 2005; Jiao, *et al.*, 2008). Hence, supplier involvement determines not only the success of product design but also operational processes, e.g. sourcing and producing. Khan, *et al.* (2008) underline the role of supplier involvement in the design process for effective supply chain risk reduction. In addition,

ESI is the one of the qualitative solutions to capacity risks and production interruptions (Tang and Musa, 2011).

Long-term co-operation which is based on a close relationship is crucial for achieving the objectives of joint product development (Hoegl and Wagner, 2005; Li, *et al.*, 2010). Sharing information, knowledge and physical resources shortens NPD time, minimizes costs as well as improves the quality of the developed products (McGinnis and Vallopra, 1999; Parker, *et al.*, 2008; Chien and Chen, 2010). Similarly, frequent communication in a friendly atmosphere as well as internal and external integration determine the success of SIPD (Chien and Chen, 2010; Flynn, *et al.*, 2010; Feng, *et al.*, 2013). Thus, it is recommended that different departments of a supplier be integrated (Birou and Fawcett, 1994; McIvor and

Humphreys, 2004) with different departments of a buyer (Maffin and Braiden, 2001; Parker, *et al.*, 2008). Companies should also consider an early stage and a higher degree of supplier involvement to get better NPD outcomes, (Bonaccorsi and Lipparini, 1994; Mikkola and Skjoett-Larsen, 2003; Klioutch and Leker, 2011), especially in the situation of designing complex and innovative products (Handfield, *et al.*, 1999).

Previous studies show that companies willingly involve suppliers that offer strategic or critical items (Handfield, *et al.*, 1999). Such partners provide their customers with unique solutions and knowledge, which significantly supports clients both when designing high quality products and in reliable manufacturing processes. Further, SIPD provides the customer with access to product technology and also facilitates compliance (Handfield, *et al.*, 1999). Thus, it leads to the reduction of such buyer's operational risks as human failures, improper procedures, or inadequate production infrastructure.

All mentioned practices, e.g. sharing resources and knowledge, frequent communication as well as participation of various departments in NPD projects, are aimed at eliminating human failures and technical or technological problems (Zsidisin and Smith, 2005; Tang, *et al.*, 2009). These kinds of interruptions have their source in operational risk (Directive 2009/138/EC). Therefore, it is hypothesized that (**Figure 1**):

H1. Supplier involvement in product development reduces a company's operational risk

### **3.2 Relation Between Supplier Involvement in Product Development and Supply Risk**

Smeltzer and Siferd (1998) advised early supplier involvement, reducing the supplier base, and developing long-term cooperation to deal with risks related to suppliers. Zsidisin and Smith (2005) proposed that ESI reduces the risk of suppliers' technical and organizational problems, suppliers' capacity constraints and even disasters at supplier facilities.

Carr, *et al.* (2008) found that SIPD can result in better operational outcomes of the supplier in terms of product quality, delivery time and cost control. The decision on supplier involvement requires detailed assessment (Handfield, *et al.*, 1999; Spina, *et al.*, 2002; Büyüközkan and Görener, 2015). Evaluation reduces uncertainties related to suppliers, such as qualitative and quantitative non-compliance of deliveries or untimely deliveries.

Authors underline the importance of co-investments and supplier development in the success of joint product development (Bozdogan, *et al.*, 1998; Fan, *et al.*, 2000; Saeed, *et al.*, 2013). Such programs are aimed at improving a supplier's performance and eliminating the possibility of the failure to meet customer requirements (Handfield, *et al.*).

In the light of the above considerations as well as the research proposals presented by Zsidisin and Smith (2005), the following hypothesis is built (**Figure 1**):

H2. Supplier involvement in product development reduces supply risk

### **3.3 The Relation Between Risk Reduction and Supply Chain Resilience**

There are various examples of situations when operational risk seriously interrupts business continuity. Lack of awareness of risk and being ill-prepared increase any negative consequences. Almost half of the surveyed large enterprises operating in Poland declared that the main cause of the most difficult crises in their supply chain was the operational risk of the company or its supplier (Wieteska, 2018c). The primary source of the crisis is very often a natural event that carries destructive power, e.g. an earthquake (Healings, 2012) or lightning (Norrman and Jansson, 2004).

Risk is defined as the combination of the probability of an event and its consequences (FERMA 2003). Risk reduction is focused on manipulating these two measures. Reducing the degree of probability needs preventive actions, e.g. personnel training, supervision of technical infrastructure, initial partner evaluation and supplier development. Dealing with the consequences involves strengthening the security of both physical assets (e.g. inventories, freight) and information. In addition, it requires business continuity plans that can be implemented whenever a crisis occurs (ISO 22301). The ability to adapt during a disruption is mainly based on flexibility and redundancy options, as well as the area of supplier relationship management (Ali, *et al.*, 2017).

Past studies underline the role of risk management in achieving supply chain resilience (Roberta Pereira, *et al.*, 2014; Chowdhury and Quaddus, 2016). Developing a risk management culture in the supply chain is regarded as one proactive supply chain resilience strategy (Tukamuhabwa, *et al.*, 2015). Chowdhury and Quaddus (2016) observed that this factor positively influences SCRES.

A reduced degree of risk (reduced probability and/or consequences) means that the probability of adverse event is assessed, mitigated and accepted, and the potential negative consequences are controlled in case of disruption. The need to anticipate and prepare for risk in order to mitigate the effects of crisis situations is reflected in the definitions of SCRES (Ponis and Koronis, 2012; Datta, 2017). Therefore, it is hypothesized that (**Figure 1**):

H3. A company's reduced operational risk positively impacts supply chain resilience

H4. Reduced supply risk positively impacts supply chain resilience.

## **4. METHODOLOGY**

### **4.1 Operationalization of The Approach**

The theoretical model covers three main areas, which are: supplier involvement in product development, risk and supply chain resilience (**Figure 1**). Operationalization of the presented approach required that each area is expressed with an adequate construct. The measurement of SIPD was proposed following the results of a systematic literature review (Wieteska, 2019a). The conducted analysis of past studies revealed that SIPD is most often quantified with the use of the three distinct dimensions:

- the extent of supplier involvement in product development (degree of involvement, level of responsibility),

- partnership practices that can be performed during NPD cooperation with suppliers, and
- extensive communication with the partner during the joint product development process.

It was decided that all three would be used in this study to achieve a comprehensive insight. Thus, SIPD is expressed with three sub-constructs (**Table 1**), i.e. degree of supplier involvement in product development (DSI), partnership (PSI) and communication (CSI) during product development.

In the research, two of the three types of supply chain risk are taken into account, i.e. supply risk and operational risk (Manuj and Mentzer, 2008). The third type (demand risk) was not considered as the research concerns a dyadic perspective (supplier-company relationship), not a triadic one (supplier-company-client relationship). The items included in the company's operational risk (OR) construct are proposed following the definition of operational risk which is presented in the European Directive 2009/138/EC. These are mainly based on the classification of internal adverse events that hinder the functioning of an organization. Operational risk also refers to information and commodity security, which is the subject of an international management standard on supply chain security (ISO 28000:2007).

The supply risk (SR) construct is built from the three items that refer to the most common difficulties: which are the punctuality and qualitative and quantitative compliance of deliveries (Handfield, *et al.*, 1999; Carr, *et al.*, 2008; Zsidisin and Smith, 2005).

Finally, the area of supply chain resilience is expressed with a construct which is adopted from Ponomarov (2012, p. 76), consisting of six variables. The reliability and validity of SCRES construct were confirmed in previous research by this scientist.

## 4.2 Sampling

Since the issues of SIPD were studied mainly on producers, the survey covered only manufacturing companies. These supply chain entities were small, medium, or large companies operating in Poland and included both domestic and international companies. Their capital varied, i.e. domestic, foreign, or mixed. Data was collected using a computer-assisted telephone interviewing (CATI) method. The source of information about potential respondents (e.g. telephone contact, address) was the Bisnode Database ([www.bisnode.pl](http://www.bisnode.pl)). The statistical sample included 10051 companies, with answers being obtained from 500 companies. The number of companies representing each sector was calculated by taking into account the principle 'probability proportional to size'.

Purposive sampling was adopted for sample selection. Chosen companies were only those entities that develop products with suppliers. In addition, emphasis was placed on the respondent's knowledge of the topic being investigated. The main filter question was whether the respondent was responsible for at least one SIPD project in the company. The respondents were top management, i.e. CEOs, members of the board, business owners, managers responsible for purchasing and supply chain management. The survey was conducted between June and July 2019.

The study involved the following six industries: production of computers, electronic and optical products;

production of electrical devices; production of machinery and devices not elsewhere classified; production of motor vehicles, lorries and articulated lorries, not including motorcycles; production of other transport equipment and production of fabricated metal products, not including machinery and equipment. These listed industries are divisions according to Statistics Poland (<https://stat.gov.pl/en/>). The above were chosen because the systematic literature review showed that they were most frequently examined in the past in the field of SIPD (Wieteska, 2019b). Furthermore, it was observed that manufacturing companies involve suppliers in developing products with complex rather than simple architecture (Handfield, *et al.*, 1999).

## 4.3 Instrument Development

The research instrument comprised all four research areas: supplier involvement in product development, supply risk, company's operational risk and supply chain resilience (**Figure 1**). In the developed questionnaire each area was expressed through statements based on previous studies. Each statement represented one observable variable measured with the five-point Likert scale (5-highly agree, 1-highly disagree). The survey was preceded by preliminary research on a sample of twelve companies representing selected industries, i.e. two companies from each industry. This was intended to assess the questionnaire in terms of its content and structure and the collected comments and remarks were included in the revised version of the questionnaire. The key to ensuring the credibility of the answers is whether the vocabulary used is understandable not only to scientists, but above all to the business practitioners to whom the questionnaire is addressed. The final research instrument and the references for each item are presented in Appendix 1.

# 5. RESEARCH RESULTS

## 5.1 Reliability and Validity

The SPSS Statistics program was used to evaluate empirical data. In the research the three following methods for data analysis and the verification of the hypotheses were adopted:

- Cronbach's alpha,
- Confirmatory factor analysis (CFA) and
- Structural Equation Modeling (SEM).

Cronbach's alpha allowed the assessment of the reliability of the scale for each latent variable (**Table 1**). The studied scales were required to have a Cronbach's alpha coefficient higher than 0.7. This condition is called the Nunnally criterion (Nunnally and Bernstein, 1994, pp.145-164; Bowling, 2002, p. 49). It was also required that removing variables from the scale would cause a decrease in the value of the Cronbach's alpha coefficient. Furthermore, it was accepted that for new constructs 0.6 is a minimal value (Cronbach, 1951 in: Brzeziński, 2005, pp.177-212). In this research, the reliability of measurement for DSI (the degree of supplier involvement) as well as for CSI (communication during supplier involvement) determined by means of Cronbach's gives an approximation of 0.7 (Hair, *et al.*, 2016, p. 7). The other constructs reach a value clearly above 0.7. Hence, based on the empirical data (500 observations), the

accuracy of the measurement of each of the hidden variables measured with Cronbach's alpha is confirmed.

It is also important that the correlation of variables with all others is > 0.4 (Nunally, 1970, pp. 132-135). Next, factor loadings should be greater than 0.5 (Fornell and Larcker,

1981; Staniec, 2018). In this research they all reached accepted values. CFA led to the removal of certain items from the constructs (Appendix 1). Nevertheless, based on the conducted analysis, the reliability and validity of each latent variable is confirmed.

**Table 1** Reliability and validity

Research area	Latent Variable	Observable Variable	Cronbach's Alpha	Factor loading
Supplier involvement in product development	Degree of supplier involvement	DSI2	0.692	0.593
		DSI5		0.702
		DSI6		0.727
		DSI7		0.704
		DSI10		0.633
	Partnership during supplier involvement	PSI3	0.791	0.695
		PSI5		0.668
		PSI6		0.692
		PSI8		0.739
		PSI9		0.637
		PSI10		0.773
	Communication during supplier involvement	CSI1	0.678	0.791
		CSI2		0.777
CSI3		0.687		
CSI5		0.595		
Risk	Company's operational risk	OP1	0.945	0.974
		OP2		0.974
	Supply risk	SR1	0.885	0.892
		SR2		0.933
		SR3		0.883
	Resilience	Supply chain resilience	SCRES1	0.855
SCRES2			0.916	
SCRES5			0.854	
SCRES6			0.692	

**5.2 Assessment of the Structural Model**

The model was estimated using the maximum likelihood estimation, assuming a multidimensional normal distribution. It was assessed using several goodness of fit tests (Table 2). In the case of the structural models, there was no reason to reject the model fit when p=0.000. In this research, root mean square error of approximation (RMSEA

= 0.098, RMSEALO = 0.092; RMSEAHl = 0.103) indicates the poor fit of the model. The quotient  $\lambda^2$  by the number of degrees of freedom = 2.234, supports the acceptability of the model. Finally, the values of GFI and AGFI are within the required thresholds. Although the model is poorly suited to the data, it can still be used in the description as it meets the minimum theoretical requirements.

**Table 2** The assessment of structural equation model in the light of goodness of fit tests

Parameter	Requirement	Value
Chi-square ( $\chi^2$ )	p<0.05	0.000
Root mean square error of approximation (RMSEA)	<1	0.098
Quotient $\lambda^2$ by the number of degrees of freedom	<5	2.234
Goodness of Fit (GFI)	>0.9	0.904
Adjusted Goodness of Fit (AGFI)	>0.9	0.900

**Table 3** Standardized values of estimated parameters in the structural model

Correlation Dependency	Estimate
Degree of supplier involvement → Company's operational risk	-0.055
Partnership during supplier involvement → Company's operational risk	-0.040
Communication during supplier involvement → Company's operational risk	0.325***
Degree of supplier involvement → Supply risk	0.042
Partnership during supplier involvement → Supply risk	0.266***
Communication during supplier involvement → Supply risk	0.050
Company's operational risk → Supply chain resilience	0.758***
Supply risk → Supply chain resilience	0.033

\*\*\*for the p<0.001

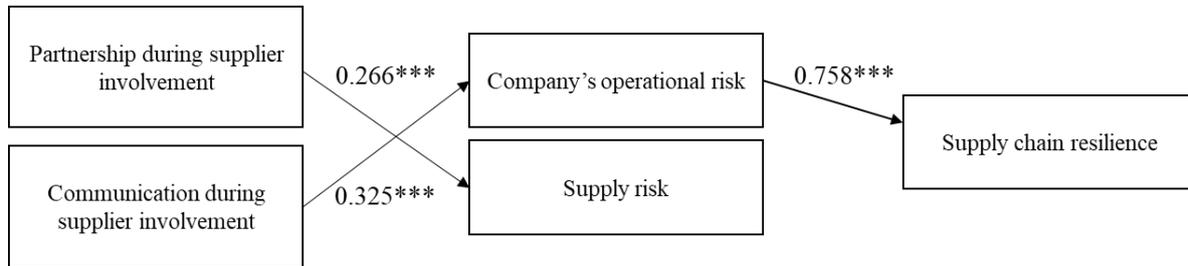
Statistically significant correlation dependencies ( $p < 0.001$ ) are identified between the following (**Table 3**):

- Communication during supplier involvement and company’s operational risk with a force of 0.325,
- Partnership during supplier involvement and supply risk with a force of 0.266,
- Company’s operational risk and supply chain resilience with a force of 0.758.

The results show that the impact of supplier involvement on supply chain risks is observed for the two following dependencies. Communication during supplier involvement (CSI) directly influences the company’s operational risk (OR), whereas partnership during supplier

involvement (PSI) has a positive impact on reducing supply risk (SR). This allows one to conclude that hypothesis H1 and hypothesis H2 can be partially supported. Next, there is a positive correlation between a company’s reduced operational risk (OR) and achieving supply chain resilience (SCRES). The study shows that hypothesis H3 is significant for  $p < 0.001$ , thus it is fully supported. Considering the cause–effect relationship between supply risk (SR) and supply chain resilience, hypothesis H4 was insignificant.

Based on the conducted analysis and results obtained (**Table 1, Table 2, Table 3**), the empirical model consists of five validate constructs and three statistically confirmed dependencies (**Figure 2**).



**Figure 2** Empirical model of the influence of supplier involvement on supply chain risks and resilience with indicated standardized path indices. The arrows indicate the estimated standardized parameters. \*\*\* represents dependencies significant for  $p < 0.001$ .

## 6. DISCUSSION

This study demonstrates that there are statistical dependencies between supplier involvement in product development, supply chain risk and resilience. In general, supplier involvement has a positive impact on reducing supply chain risks. This allows the confirmation of certain observations that have appeared in prior qualitative research. Khan, *et al.* (2008) advised that working with suppliers when designing products effectively enables the management of supply chain risk. Tang, *et al.* (2009) provided several key NPD lessons to minimize supply chain risk. They mainly underlined the need for close supplier-customer cooperation during new product development.

Risks in the supply chain are divided into three types (Johnson, 2001; Zsidisin, 2002; Manuj and Mentzer, 2008). As SIPD concerns cooperation between an enterprise and its suppliers, this article focuses on two types of risk, namely a company’s operational risk and supply risk. The results show that both risks are mitigated if particular activities and practices are carried out while developing products with suppliers. Khan, *et al.* (2008) emphasized the role of communication and collaboration in improving the design process, which can result in effective supply chain risk management. The statistical analyzes conducted in this paper present more detailed observations proving that frequent, intensive and communication, conducted in a friendly atmosphere, has a positive impact on reducing a company’s operational risk. This can be explained by the fact that a climate for good communication facilitates the open sharing of knowledge and information and thus increases trust between partners (Tavani, *et al.*, 2013). In turn, trust has a positive impact on business performance (Davis, *et al.*, 2000). SIPD is positively linked to the operational performance of a company, which is understood, among others, as flexibility when responding to a customer’s needs

and timely execution of orders (Feng, *et al.*, 2013). However, a high level of customer service, which avoids delays and quality problems, is possible when the risk of human failures or failed processes is efficiently reduced. Open communication with suppliers that possess greater technological experience is particularly beneficial for a company. The knowledge obtained in this way allows the customer to design efficient manufacturing processes, the output of which will be a high-quality product (Handfield, *et al.*, 1999). Interestingly, Petersen, *et al.*, (2003) observed that “increased knowledge of a supplier is more likely to result in greater information sharing and involvement of the supplier in the product development process”.

The conducted quantitative study also allowed the recognition that supplier involvement based on close cooperation has a positive impact on reducing supply risk. According to the research results, partnership practices implemented during NPD have a positive impact on the risk of untimely deliveries and the risk of poor-quality supplies. Risk hampers the effective achievement of goals (FERMA 2003; COSO 2004, p. 25) and therefore may significantly disrupt a supplier’s operational success. This thread concurs with the study of Carr, *et al.* (2008), who recognized a positive link between supplier involvement in (new) product development and supply performance.

The research shows that one of the practices that has a significant impact on supply risk is mutual support - understood as partner evaluation, education, and improvement. Tang, *et al.* (2009) underline that selection of the appropriate supplier enabled the reduction of the risk of the partner not having the right capabilities. Companies use various criteria for supplier assessment (Handfield, *et al.*, 1999). This way, they aim to ensure both effective joint product development as well as smooth collaboration during full-scale production which requires high-quality components and punctual deliveries. Supplier development

is recommended in order to achieve better effects of NPD (Fun, *et al.*, 2000), although this study demonstrates that partner education and training also contribute to minimizing supply risk.

The research reveals that another SIPD practice influencing supply risk is establishing cross-functional NPD teams. The literature shows that companies are willing to involve a supplier's employees in the NPD process (Birou and Fawcett, 1994). However, effective cooperation in a cross-functional team is determined by various factors, e.g. competences and "fit" of the members (Wagner and Hoegl, 2006). Takeishi (2001) observed that mature internal and external coordination leads to better component quality. However, the quality of the supplier's performance is determined by effective and efficient supplier value adding processes.

Supplier involvement in product development should be based on a mutual willingness to develop a long-term relationship (Primo and Amundson, 2002; Song and Di Benedetto, 2011). This study shows that such an alignment supports the reduction of supply risk too. Similarly, it also confirmed that joint product development based on sharing technical knowledge and cost information determines not only project outcomes (McGinnis and Vallopra, 1999; Parker, *et al.*, 2008; Chien and Chen, 2010) but also brings long-term effects in the form of reliable supplies during full scale production. Interestingly, Zsidisin and Smith (2005) proposed that ESI may reduce risks related to supplier capacity constraints.

In recent years special attention has been paid to the issue of supplier timing and responsibility in NPD. Many scientists have observed the positive impact of the degree of supplier involvement on NPD outcomes (Petersen, *et al.*, 2005; Handfield and Lawson, 2007; Lai, *et al.*, 2011). This study, however, does not confirm any significant dependence between this aspect and supply chain risks, meaning that supply risk and operational risk are not affected by the level of responsibility and the extent of the supplier's involvement at individual stages of the NPD. However, this area requires further investigation, especially in the context of what stage the supplier becomes involved. The literature indicates that including suppliers in the early stages of NPD brings a number of benefits (McGinnis and Vallopra, 1999; Mikkola and Skjoett-Larsen, 2003; Zsidisin and Smith, 2005; Wagner 2012).

Another interesting fact that the study showed is that extensive communication during joint product development impacts only operational risk, while partnership practices influence supply risk. The considerations in this paper lead to the reflection that the factors that may affect a given situation might be related to supplier-customer dependencies, different negotiation powers or the know-how of partners and thus also levels of operational risk for the supplier and the company. It is possible that supplier risk reduction and operational risk reduction require different incentives during joint product development. However, this thread requires further investigation.

The study also allowed the analysis of the relation between supply chain risk and supply chain resilience. The results show that reduced operational risk is positively connected to SCRES. This confirmed dependence rejects the doubts of Roberta Pereira, *et al.* (2014), who question whether risk reduction positively affects supply chain

resilience. However, they consider risk only as a likelihood, whereas risk is a combination of the likelihood and the negative impact of disruption. Furthermore, it is noticeable that goals of SCRES which are aimed at preparing for unexpected negative events rather than reducing the likelihood of their occurrence (Ponis and Koronis, 2012; Hohenstein, *et al.*, 2015). Of course, the risk of certain events cannot be reduced (e.g. events caused by forces of nature), however the concept of SCRES goes beyond catastrophic situations. The results of this research show that ensuring resilience is not just about providing protection as part of proactive measures. Preventive actions against the occurrence of an event are equally important. This approach, in turn, is reflected in other works on SCRES (Kamalahmadi and Parast, 2016; Ali, *et al.*, 2017).

Surprisingly, the research results show that there is no significant dependence between reduced supply risk and supply chain resilience. This somewhat excludes the importance of the domino effect for supply chain resilience. Further considerations are required in this area, as the literature clearly shows that problems with the continuity of supplies can cause huge losses to the customer (Norrman and Jansson, 2004; Healings, 2012) and the spread of disruptions along supply chain processes is undisputed (Wieteska, 2018c). It is presumed that the lack of relation between supply risk and supply chain resilience may result from the adopted SCRES construct. Namely, the items forming this construct are focused more on a single company's perspective and the internal supply chain rather than supplier-customer relationships. In the future, it is suggested that a more comprehensive SCRES construct is used that also clearly refers to the structure, processes, and abilities of the external supply chain.

Finally, the research shows that supplier involvement in product development enhances the creation/success of SCRES. The considerations on the relation between SIPD and supply chain risks allow one to point out here the importance of such practice as supplier assessment. This conclusion is supported by the fact that Tukamuhabwa, *et al.* (2015) distinguish the selection of an appropriate supplier among proactive SCRES strategies. In turn, Roberta Pereira, *et al.* (2014), following a systematic literature review, listed information sharing, collaboration, and integration as important SCRES enablers.

## 7. CONCLUSIONS

The objective of the presented research was to identify dependences between SIPD, risk and supply chain resilience. Despite many studies on supplier involvement, there is a lack of valid and reliable measurement models presenting how it affects supply risk, operational risk and SCRES. This paper has both theoretical and managerial implications for this area. First, based on the in-depth literature review, the conducted study provides a valuable insight by developing a research model on the impact of SIPD on supply chain risks and resilience. This type of dependencies had not been studied before. Being a novel input for the literature on developing products in supply chains, the research results and discussion contribute to the theory.

The conducted analyses allowed the confirmation of several constructs. The structure (content) of SIPD latent variables is an important source of information about desired

practices that determine effective supply chain risk reduction. In this way, the study provides top management with valuable knowledge on the, generally accepted, NPD cooperation and communication practices that significantly influence supply risk and a company's operational risk and, thus, SCRES. The research results should encourage companies that want to manage supply chain risk more effectively to integrate suppliers into product and process design. The paper also gives a deeper insight into such related aspects as product development, supply chain design, risks, and joint product development. In addition, the presented work underlines the importance of SIPD not only for better NPD outcomes but also for operational success which results in less supply chain vulnerability. In an era in which environmental uncertainty is growing and time is becoming ever more important for ensuring competitiveness in the global market, risk identification and reduction should take place as early as possible in the product's life cycle.

There are of course limitations of this study, including the subjectivity of respondents when answering. When carrying out a survey, however, it is difficult not to be exposed to it. Secondly, the operationalization of variables is usually burdened with a degree of bias. Its reduction requires an in-depth literature review, which was carried out before constructing the final structure of theoretical model. A serious limitation to the design of this study was the small number of papers directly linking supplier involvement in product development with supply chain risk reduction and supply chain resilience. This article is intended to raise this topic. Nevertheless, future studies should continue to seek theoretical and practical knowledge on the role of joint product development for designing resilient supply chains.

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## REFERENCES

- Ali, A., Mahfouz, A., & Arisha, A. (2017). Analysing supply chain resilience: integrating the constructs in a concept mapping framework via a systematic literature review. *Supply Chain Management: An International Journal*, 22(1), pp. 16-39.
- Asmus, D., Griffin, J. (1993). *Harnessing the power of your suppliers*. The McKinsey Quarterly, (3), pp. 63-78.
- Birou, L. M. and Fawcett, S. E. (1994). Supplier Involvement in Integrated Product Development: A Comparison of US and European Practices. *International Journal of Physical Distribution & Logistics Management*, 25(5), pp. 4-14.
- Bonaccorsi, A., & Lippardini, A. (1994). Strategic partnerships in new product development: an Italian case study. *Journal of product innovation management*, 11(2), pp. 134-145.
- Boothroyd, G. (1994). Product design for manufacture and assembly. *Computer-Aided Design*, 26(7), pp. 505-520.
- Bowling, A. (2014). *Research methods in health: investigating health and health services*. McGraw-hill education (UK).
- Bozdogan, K., Deyst, J., Hoult, D., Lucas, M. (1998). Architectural innovation in product development through early supplier integration. *R&D Management*, 28, pp. 163-173.
- Cagli, A., Kechidi, M., Levy, R. (2012). Complex product and supplier interfaces in aeronautics. *Journal of Manufacturing Technology Management*, 23 (6), pp. 717-732.
- Büyüközkan, G., Görener, A. (2015). Evaluation of product development partners using an integrated AHP-VIKOR model. *Kybernetes*, 44(2), pp. 220-237.
- Carr, A. S., Kaynak, H., Hartley, J. L., Ross, A. (2008). Supplier dependence: impact on supplier's participation and performance. *International Journal of Operations & Production Management*, 28(9), pp. 899-916.
- Ceschin, F., Gaziulusoy, I. (2016). Evolution of design for sustainability: From product design to design for system innovations and transitions. *Design studies*, 47, pp. 118-163.
- Chien, S. H., Chen, J. J. (2010). Supplier involvement and customer involvement effect on new product development success in the financial service industry. *The Service Industries Journal*, 30(2), pp. 185-201.
- Chiu, M. C., Kremer, G. E. O. (2013). An investigation on centralized and decentralized supply chain scenarios at the product design stage to increase performance. *IEEE Transactions on Engineering Management*, 61(1), pp. 114-128.
- Christopher, M., Peck, H., Towill, D. (2006). A taxonomy for selecting global supply chain strategies. *The International Journal of Logistics Management*, 17(2), 277-287.
- Chowdhury, M. M. H., Quaddus, M. (2016). Supply chain readiness, response and recovery for resilience. *Supply Chain Management: An International Journal*, 21(6), 709-731.
- Cooper M. C., Lambert D.M., Pagh J. D. (1997). Supply Chain Management: More Than a New Name for Logistics. *International Journal of Logistics Management*, (8), pp. 1-14.
- Chopra, S., Sodhi, M. S. (2004). *Supply-chain breakdown*. MIT Sloan Management Review, 46(1), pp. 53-61.
- COSO (2004). *Enterprise Risk Management Framework*.
- Culley, S. J., Boston, O. P., McMahon, Ch. A. (1999). Suppliers in New Product Development: Their Information and Integration. *Journal of Engineering Design*, 10(1), pp. 59-75.
- Danese, P., Filippini, R. (2010). Modularity and the impact on new product development time performance. *International Journal of Operations & Production Management*, 30(11), pp. 1191-1209.
- Datta, P. (2017). Supply network resilience: a systematic literature review and future research. *The International Journal of Logistics Management*, 28(4), pp. 1387-1424.
- Davis, J. H., Schoorman, F. D., Mayer, R. C., & Tan, H. H. (2000). The trusted general manager and business unit performance: Empirical evidence of a competitive advantage. *Strategic management journal*, 21(5), pp. 563-576.
- Directive 2009/138/EC. *Directive on the taking-up and pursuit of the business of Insurance and Reinsurance*, European Parliament and of the Council of 25 November 2009.
- Dowlatshahi, S. (1998). Implementing early supplier involvement: a conceptual framework. *International Journal of Operations & Production Management*, 18(2), pp. 143-167.
- Drake, P. R., Myung Lee, D., Hussain, M. (2013). The lean and agile purchasing portfolio model. *Supply Chain Management: An International Journal*, 18(1), pp. 3-20.
- Er Kara, M., Firat, O., Ümit, S. (2018). Supplier risk assessment based on best-worst method and k-means clustering: a case study. *Sustainability*, 10(4), 1066.
- Fan, I. S., Russell, S., Lunn, R. (2000). Supplier knowledge exchange in aerospace product engineering. *Aircraft Engineering and Aerospace Technology*, 72(1), 14-17.
- FERMA (2003). AIRMIC/ALARM/IRM:2002.
- Fiksel, J. (2009). *Design for environment: a guide to sustainable product development*. McGraw Hill Professional.
- Flynn, B. B., Huo, B., Zhao, X. (2010). The impact of supply chain integration on performance: A contingency and configuration approach. *Journal of operations management*, 28(1), pp. 58-71.

- Fornell, C., Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, 18(1), pp. 39-50.
- Gölgeci, I., Ponomarov, S. Y. (2015). How does firm innovativeness enable supply chain resilience? The moderating role of supply uncertainty and interdependence. *Technology Analysis & Strategic Management*, 27(3), pp. 267-282.
- Hair Jr, J. F., Hult, G. T. M., Ringle, C., Sarstedt, M. (2016). *A primer on partial least squares structural equation modeling (PLS-SEM)*. Sage publications.
- Hallikas J., Puumalainen K., Vesterinen T. Virolainen V-M., (2005). Risk-based classification of supplier relationships. *Journal of Purchasing & Supply Management*, 11, pp. 72-82.
- Handfield, R. B., Ragatz, G. L., Petersen, K. J., Monczka, R. M. (1999). *Involving Suppliers in New Product Development*. California Management Review, 42(1), pp. 59-82.
- Handfield R. B., Lawson B., (2007). Integrating suppliers into new product development. *Research-Technology Management*, 5(5), pp. 44-51.
- Hartley, J. L., Zirger, B. J., Kamath, R. R. (1997). Managing the buyer-supplier interface for on-time performance in product development. *Journal of Operations Management*, (15), pp. 57-70.
- Healings, S. (2012). Making supply chain risk management a priority in 2012. *Surface Mount Technology*, 27, pp. 26-32.
- Hoegl, M., Wagner, S. M. (2005). Buyer-supplier collaboration in product development projects. *Journal of Management*, 31(4), pp. 530-548.
- Hohenstein N. O., Feisel E., Hartmann E., Giunipero, L. (2015). Research on the phenomenon of supply chain resilience: a systematic review and paths for further investigation. *International Journal of Physical Distribution & Logistics Management*, 45(1/2), pp. 90-117.
- Huang, G. Q., Mak, K. L., Humphreys, P.K. (2003). A new model of the customer-supplier partnership in new product development. *Journal of Materials Processing Technology*, (138), pp. 301-305.
- ISO 22301:2019 (2019). Security and resilience – Business continuity management systems – Requirements. International Organization for Standardization.
- ISO 31000:2018 (2018). Risk management – Principles and guidelines. International Organization for Standardization.
- ISO/IEC 27001:2013 (2013). Information technology – security techniques – information security management systems – requirements. International Organization for Standardization.
- ISO 28000:2007 (2007). Specification for security management systems for the supply chain. International Organization for Standardization.
- Jayaram, J. (2008). Supplier involvement in new product development projects: dimensionality and contingency effects. *International Journal of Production Research*, 46(13), pp. 3717-3735.
- Jiao, Yuan-Yuan, Du Jun, Jiao, R. J. Butler, D. L. (2008). Operational implications of early supplier involvement in semiconductor manufacturing firms: A case study. *Journal of Manufacturing Technology Management*, 1(8), pp. 913-932.
- Johnson, M.E., (2001). Learning from toys: lessons in managing supply chain risk from toy industry. *California Management Review* 43(3), pp. 106-124.
- Jüttner, U. (2005). Supply chain risk management: Understanding the business requirements from a practitioner perspective. *The International Journal of Logistics Management*, 16 (1), pp. 120-141.
- Jüttner, U., Peck, H., Christopher, M. (2003). Supply chain risk management: outlining an agenda for future research. *International Journal of Logistics: Research and Applications*, 6(4), pp. 197-210.
- Kamalahmadi, M., Parast, M. M. (2016). A review of the literature on the principles of enterprise and supply chain resilience: Major findings and directions for future research. *International Journal of Production Economics*, 171, pp. 116-133.
- Khan, O., Christopher, M., Burnes, B. (2008). The impact of product design on supply chain risk: a case study. *International Journal of Physical Distribution & Logistics Management*, 38(5), pp. 412-432.
- Khan, O., Christopher, M., Creazza, A. (2012). Aligning product design with the supply chain: a case study. *Supply Chain Management: An International Journal*, 17(3), pp. 323-336.
- Klioutch, I., Leker, J. (2011). Supplier involvement in customer new product development: new insights from the supplier's perspective. *International Journal of Innovation Management*, 15(01), pp. 231-248.
- Krause, D. R., Handfield, R. B., Scannell, T. V. (1998). An empirical investigation of supplier development: reactive and strategic processes. *Journal of Operations Management*, 17(1), 39-58.
- Lai, C. S., Chen, C. S., Chiu, C. J., Pai, D. C. (2011). The impact of trust on the relationship between inter-organisational collaboration and product innovation performance. *Technology Analysis & Strategic Management*, 23(1), pp. 65-74.
- Lakemond N., Berggren Ch. van Weele A., (2006). Coordinating supplier involvement in product development projects: a differentiated coordination typology. *R&D Management*, 36(1), pp. 55-66.
- Li, S., Gu, S., Wang, Q. (2010). An empirical study on the influencing factors of supplier involvement in new product development. *Frontiers of Business Research in China*, 4(3), pp. 451-484.
- Lu, Q., Wood, L. (2006). The refinement of design for manufacture: inclusion of process design. *International Journal of Operations & Production Management*, 26(10), pp. 1123-1145.
- Luzzini, D., Amann, M., Caniato, F., Essig, M., Ronchi, S. (2015). The path of innovation: purchasing and supplier involvement into new product development. *Industrial Marketing Management*, 47, pp. 109-120.
- Lyu, J., Chang, L. Y. (2007). Early involvement in the design chain – a case study from the computer industry. *Production Planning and Control*, 18(3), pp. 172-179.
- Maffin, D., Braiden, P. (2001). Manufacturing and supplier roles in product development. *International Journal of Production Economics*, 69(2), pp. 205-213.
- Manuj I., Mentzer J.T. (2008). Global supply chain risk management strategies. *International Journal of Physical Distribution & Logistics Management*, 38(3), pp. 192-223.
- Mason-Jones, R., Naylor, B., Towill, D. R. (2000). Lean, agile or leagile? Matching your supply chain to the marketplace. *International Journal of Production Research*, 38(17), pp. 4061-4070.
- Melnyk, S. A., Closs, D. J., Griffis, S. E., Zobel, C. W., Macdonald, J. R. (2014). *Understanding supply chain resilience*. Supply Chain Management Review, 18(1), 34-41.
- McGinnis, M. A., Vallopra, R. M. (1999). Purchasing and supplier involvement: issues and insights regarding new product success. *Journal of Supply Chain Management*, 35(2), pp. 4-15.
- McIvor, R., Humphreys, P. (2004). *Early supplier involvement in the design process: lessons from the electronics industry*. Omega 32, pp. 179-199.
- Melander, L. (2014). Buyer-supplier collaboration in new product development between two equally powerful firms: a case study of ABB and SKF. *Operations and Supply Chain Management*, 7(3), pp. 107-113.
- Mikkola, J. H., Skjoett-Larsen, T. (2003). Early supplier involvement: implications for new product development outsourcing and supplier-buyer interdependence. *Global Journal of Flexible Systems Management*, 4(4), pp. 31-41.

- Nishat Faisal, M., Banwet, D. K., Shankar, R. (2006). Supply chain risk mitigation: modeling the enablers. *Business Process Management Journal*, 12(4), pp. 535-552.
- Norrman, A., Jansson, U. (2004). Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *International Journal of Physical Distribution & Logistics Management*, 34(5), pp. 434-456.
- Nunally, J. C. (1970). *Introduction to psychological measurement*. New York: McGraw-Hill.
- Nunnally J. C. Bernstein I. H. (1994). *Psychometric theory*. Third edition. McGraw-Hill. New York.
- Ocicka, B. (2017). Rozwój innowacji otwartych w świetle strategii zarządzania łańcuchem dostaw. *Nauki o Zarządzaniu*, (31), pp. 33-39.
- O'Driscoll, M. (2002). Design for manufacture. *Journal of Materials Processing Technology*, 122(2-3), pp. 318-321.
- Parker, D. B., Zsidisin, G. A., Ragatz, G. L. (2008), Timing and extent of supplier integration in new product development: a contingency approach, *Journal of Supply Chain Management*, Vol. 44, No. 1, pp. 71-83.
- Pashaei, S., Olhager, J. (2015). Product architecture and supply chain design: a systematic review and research agenda. *Supply Chain Management: An International Journal*, 20(1), pp. 98-112.
- Petersen, K. J., Handfield, R. B., Ragatz, G. L. (2003). A model of supplier integration into new product development. *Journal of Product Innovation Management*, 20(4), 284-299.
- Petersen, K. J., Handfield, R. B. and Ragatz, G. L., (2005). Supplier integration into new product development: coordinating product, process and supply chain design. *Journal of Operations Management*, 23, pp. 371-388.
- Pfohl, H. C., Gallus, P., Thomas, D. (2011). Interpretive structural modelling of supply chain risks. *International Journal of Physical Distribution & Logistics Management*, 41(9), pp. 839-859.
- Ponis, S. T., Koronis, E. (2012). Supply Chain Resilience? Definition of concept and its formative elements. *The Journal of Applied Business Research*, 28(5), pp. 921-935.
- Ponomarov, S. (2012). *Antecedents and consequences of supply chain resilience: a dynamic capabilities perspective*, Doctoral Dissertation, University of Tennessee, Knoxville.
- Ponomarov, S. Y., Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. *The International Journal of Logistics Management*, 20(1), pp. 124-143.
- Ragatz, G. L., Handfield, R. B., Petersen, K. J. (2002). Benefits associated with supplier integration into new product development under conditions of technology uncertainty. *Journal of Business Research*, 55(5), pp. 389-400.
- Rice, J. B., Caniato, F. (2003). *Building a secure and resilient supply network*. *Supply Chain Management Review*, 7(5), pp. 22-30.
- Roberta Pereira, C., Christopher, M., Lago Da Silva, A. (2014). Achieving supply chain resilience: the role of procurement. *Supply Chain Management: an international journal*, 19(5/6), pp. 626-642.
- Rocchi, S. (2005). *Enhancing sustainable innovation by design: An approach to the co-creation of economic, social and environmental value* (Doctoral dissertation, Erasmus University Rotterdam).
- Smeltzer, L. R., Siferd, S. P. (1998). Proactive supply management: the management of risk. *International Journal of Purchasing and Materials Management*, 34(4), pp. 38-45.
- Song, M., Di Benedetto, C. A. (2008). Supplier's involvement and success of radical new product development in new ventures. *Journal of Operations Management*, 26(1), pp. 1-22.
- Spina, G., Verganti, R., Zotteri, G. (2002). Factors influencing co-design adoption: drivers and internal consistency. *International Journal of Operations & Production Management*, 22(12), pp. 1354-1366.
- Sroufe, R., Curkovic, S., Montabon, F., Melnyk, S. A. (2000). The new product design process and design for environment: "Crossing the chasm". *International Journal of Operations & Production Management*, 20(2), pp. 267-291.
- Stalk Jr, G., Hout, T. M. (1990). *Competing against time*. *Research-Technology Management*, 33(2), pp. 19-24.
- Staniec, I. (2018). Technological Entrepreneurship: How does Environmental Turbulence Impact upon Collaboration Risk?. *Sustainability*, 10(8), pp. 27-62.
- Swink, M. (1999). Threats to new product manufacturability and the effects of development team integration processes. *Journal of Operations Management*, 17(6), pp. 691-709.
- Svensson G., (2004). Key areas, causes and contingency planning of corporate vulnerability in supply chains. A qualitative approach, *International Journal of Physical Distribution & Logistics Management*, 34(9), pp. 728-748.
- Takeishi, A. (2001). Bridging inter-and intra-firm boundaries: management of supplier involvement in automobile product development. *Strategic Management Journal*, 22(5), pp. 403-433.
- Tang, C. S. (1999). Supplier relationship map. *International Journal of Logistics: Research and Applications*, 2(1), pp. 39-56.
- Tang, D., Eversheim, W., Schuh, G. (2004). A new generation of cooperative development paradigm in the tool and die making branch: strategy and technology. *Robotics and Computer-Integrated Manufacturing*, (20), pp. 301-311.
- Tang, O., Musa, S. N. (2011). Identifying risk issues and research advancements in supply chain risk management. *International Journal of Production Economics*, 133(1), pp. 25-34.
- Tavani, S. N., Sharifi, H., Ismail, H. S. (2014). A study of contingency relationships between supplier involvement, absorptive capacity and agile product innovation. *International Journal of Operations & Production Management*, 34(1), pp. 65-92.
- Tavani, S. N., Sharifi, H., Soleimanof, S., Najmi, M. (2013). An empirical study of firm's absorptive capacity dimensions, supplier involvement and new product development performance. *International Journal of Production Research*, 51(11), pp. 3385-3403.
- Tukamuhabwa, B. R., Stevenson, M., Busby, J., Zorzini, M. (2015). Supply chain resilience: definition, review and theoretical foundations for further study. *International Journal of Production Research*, 53(18), pp. 5592-5623.
- Ülkü, S. and Schmidt, G. M. (2011). Matching product architecture and supply chain configuration. *Production and Operations Management*, 20 (1), pp. 16-31.
- Van der Valk, W., Wynstra, F. (2005). Supplier involvement in new product development in the food industry. *Industrial Marketing Management*, 34(7), pp. 681-694.
- Wagner, S. M. (2012). Tapping supplier innovation. *Journal of Supply Chain Management*, 48(2), pp. 37-52.
- Wagner, S. M., Hoegl, M. (2006). Involving suppliers in product development: Insights from R&D directors and project managers. *Industrial marketing management*, 35(8), pp. 936-943.
- Wang, M., Jie, F., Abareshi, A. (2014). The measurement model of supply chain uncertainty and risk in the Australian courier industry. *Operations and Supply Chain Management*, 7(3), pp. 89-96.
- Wieteska G. (2018a), Business Impact Analysis of supply chain disruptions, *Proceedings of The 8th international conference on Management, Economics and Humanities* (978-6-0982-3914-0), Diamond Scientific Publication, Wilno 2018, pp. 110-119. <https://www.dpublication.com/proceeding/8th-icmeh/#Table-of-Contents>
- Wieteska G. (2018b). Design of resilient supply chains. *Economic and Social Development*, (1849-7535), pp. 571-578.

- Wieteska, G. (2018c). The domino effect - disruptions in supply chains. *LogForum*, 14 (4), pp. 495-506.
- Wieteska G., (2019a). How to measure the supplier involvement?, *Material Economy and Logistics Journal*, 8, pp. 29-39.
- Wieteska G., (2019b). *Supplier involvement in product development: a systematic literature review and future research*. CSCMP European Conference and ERS, Warsaw, May 16-17, 2019.
- Wieteska-Rosiak, B. (2020). Real Estate Sector in the Face of Climate Change Adaptation in Major Polish Cities. *Real Estate Management and Valuation*, 28(1), pp. 51-63.
- Wilbers, M. (2015). *Supply Chain Innovation*. Academic Service.
- Winner, R. I., Pennell, J. P., Bertrand, H. E. Slusarczyk, M. M. (1988). The role of concurrent engineering in weapons system acquisition (No. IDA-R-338). Institute for Defence Analyses Alexandria VA.
- Zsidisin, G. A. (2002). Defining supply risk: A grounded theory approach. *Proceedings from the Decision Sciences Institute Annual Meeting*, San Diego, CA, pp. 9-12.
- Zsidisin, G. A. (2003). Managerial perceptions of supply risk. *Journal of Supply Chain Management*, 39(4), pp. 14-26.
- Zsidisin, G. A., Panelli, A., Upton, R. (2000). Purchasing organization involvement in risk assessments, contingency plans, and risk management: an exploratory study. *Supply Chain Management: An International Journal*, 5(4), pp. 187-198.
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## APPENDIX 1

**Table 1** Research instrument: survey questions and references

Construct	Item	References
Degree of supplier involvement	Question: To what extent do you engage the supplier in product development at individual stages? Scale: 1-5 Answers: 1 – very low 5 – very high	
	DSI1*	Idea generation and screening the ideas Hartley Zirger and Kamath (1997), Handfield <i>et al.</i> (1999), Parker Zsidisin and Ragatz (2008), Klioutch and Leker (2011)
	DSI2	Technical and business assessment Handfield <i>et al.</i> (1999), Mclvor and Humphreys (2004), Danilovic (2006), Spaulding and Wood (2006), Parker Zsidisin and Ragatz (2008), Klioutch and Leker (2011)
	DSI3*	Product concept development Handfield <i>et al.</i> (1999), Wynstra Weggemann and Van Weele (2001), Mclvor and Humphreys (2004)
	DSI4*	Product design and engineering Handfield <i>et al.</i> (1999), Wynstra Weggemann and Van Weele (2001), Mclvor and Humphreys (2004), Cantarello <i>et al.</i> (2011), Klioutch and Leker (2011)
	DSI5	Technological process design Wagner (2012), Lyu and Chang (2007)
	DSI6	Planning and control of production processes Mclvor and Humphreys (2004), Kähkönen Lintukangas and Hallikas (2015)
	DSI7	Prototype building, test and pilot Handfield <i>et al.</i> (1999), Wynstra Weggemann and Van Weele (2001), Jayaram (2008), Wagner (2012)
	DSI8*	Supply chain design in the sense of selection of supply sources or distribution channels Wagner (2012)
	DSI9*	Commercialization of product Spaulding and Woods (2006), Cantarello <i>et al.</i> (2011), Najafi <i>et al.</i> (2013)
	DSI10	Full-scale production in the sense of production development and improvement Mclvor and Humphreys (2004), Sjödin and Eriksson (2010), Cagli Kechidi and Levy (2012)
Partnership during supplier involvement	Question: To what extent do you agree with the below statement? Scale: 1-5 Answers: 1 – very low 5 – very high	
	PSI1*	Cooperation with the supplier was based on partner relations Hoegl and Wagner (2005), Li Gu and Wang (2010), Wagner (2012)
	PSI2*	Cooperation with the supplier was based on jointly set goals Hoegl and Wagner (2005), Parker Zsidisin and Ragatz (2008), Wagner (2010), Kähkönen Lintukangas and Hallikas (2015)
	PSI3	Cooperation with the supplier was based on mutual willingness to develop a long-term relationship Primo and Amundson (2002), Song and Di Benedetto (2011)
	PSI4*	Cooperation with the supplier was based on equitable risk and reward sharing McGinnis and Vallopra (1999)
	PSI5	Cooperation with the supplier was based on sharing such knowledge as technical/ technological McGinnis and Vallopra (1999), Hoegl and Wagner (2005), Jayaram (2008), Chien and Chen (2010)
	PSI6	Cooperation with the supplier was based on sharing cost information McGinnis and Vallopra (1999), Hoegl and Wagner (2005), Jayaram (2008), Chien and Chen (2010)
	PSI7*	Cooperation with the supplier was based on the sharing physical assets, for example plant or only equipment Birou and Fawcett (1994), Bozdogan <i>et al.</i> 1998), McGinnis and Vallopra (1999), Parker Zsidisin and Ragatz (2008)
	PSI8	Cooperation between the company's employees and the supplier's employees was very close. For example, product development cross functional team consisted of employees of the company and the supplier Fan Russel and Run (2000), Primo and Amundson (2002)

**Table 1** Research instrument: survey questions and references (cont.)

Construct	Item		References
Partnership during supplier involvement	PSI9	Cooperation with the supplier was based on mutual supporting in the improvement of e.g. quality, production capacity, through the specific activities: education and training programs, evaluations, audits	Birou and Fawcett (1994), Ragatz Handfield and Petersen (2002)
	PSI10	Cooperation with the supplier involved various levels of management, e.g. strategic and operational	McGinnis and Vallopra (1999), McIvor Humphreys and Cadden (2006), Van Echtelt Wynstra and van Weele (2007), Van Echtelt <i>et al.</i> (2008)
Communication during supplier involvement	Question: To what extent do you agree with the below statement? Scale: 1-5 Answers: 1 – very low 5 – very high		
	CSI1	Communication was frequent	Hartley, Zirger and Kamath (1997), Culley, Boston and McMahon (1999) Hoegl and Wagner (2005); Jayaram (2008)
	CSI2	Communication was intensive	Tavani <i>et al.</i> (2013), Hoegl and Wagner, (2005)
	CSI3	Communication was in friendly atmosphere	Wagner and Hoegl (2006)
	CSI4*	Communication involved employees from various departments of the company and employees from various departments of the supplier	Birou and Fawcett (1994), Dowlatshahi, (1998), Swink (1999), Maffin and Braiden, (2001), Lakemond, Berggren and van Weele (2006), Parker, Zsidisin and Ragatz (2008)
	CSI5	Cooperation with the supplier was based on communication using traditional methods, which can be a telephone, fax or direct meetings	Birou and Fawcett (1994), Hartley, Zirger and Kamath (1997), Culley, Boston and McMahon (1999)
	CSI6*	Cooperation with the supplier was based on communication with the use of advanced information and communication tools	Tang, Eversheim and Schuh (2004), Huang, Mak and Humphreys (2003)
Company's operational risk	Question: To what extent do you agree with the below statement? Scale: 1-5 Answers: 1 – very low 5 – very high		
	OP1	SI reduces risk of personnel failures	Risk type: directive 2009/138/EC
	OP2	SI reduces risk of inadequate or failed internal processes	Risk type: directive 2009/138/EC
	OP3*	SI reduces risk of machine breakdowns	Risk type: directive 2009/138/EC
	OP4*	SI reduces risk related to the product (commodity) security	Risk type: ISO 28000:2007, ISO/IEC 27001:2013
	OP5*	SI reduces risk related to the information security	Risk type: ISO 28000:2007, ISO/IEC 27001:2013
Supply risk	Question: To what extent do you agree with the below statement? Scale: 1-5 Answers: 1 – very low 5 – very high		
	SR1	SI reduces risk of untimely deliveries	Handfield <i>et al.</i> (1999)
	SR2	SI reduces risk of poor technical quality of deliveries	Handfield <i>et al.</i> (1999), Zsidisin and Smith (2005)
	SR3	SI reduces risk of quantitative non-compliance in deliveries	Handfield <i>et al.</i> (1999), Zsidisin and Smith (2005)
Supply chain resilience	Question: To what extent do you agree with the below statement? Scale: 1-5 Answers: 1 – very low 5 – very high		
	SCRES1	Our firm's supply chain is able to adequately respond to unexpected disruptions by quickly restoring its product	Construct adopted from Ponomarov (2012, p. 76)
	SCRES2	Our firm's supply chain can quickly return to its original state after being disrupted	
	SCRES3*	Our firm's supply chain can move to a new, more desirable state after being disrupted	
	SCRES4*	Our firm's supply chain is well prepared to deal with financial outcomes of supply chain disruptions	

**Table 1** Research instrument: survey questions and references (cont.)

Construct	Item		References
Supply chain resilience	SCRES5	Our firm's supply chain has the ability to maintain a desired level of control over structure and function at the time of disruption	Construct adopted from Ponomarov (2012, p. 76)
	SCRES6	Our firm's supply chain has the ability to extract meaning and useful knowledge from disruptions and unexpected events	

\* Item dropped after CFA

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