How does uncertainty affect workplace accidents? Exploring the role of information sharing in manufacturing networks

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Abstract

Purpose – The purpose of this paper is to assess the influence of uncertainty on workplace accidents at the plant level. Furthermore, this study explores such relation in complex settings (i.e. manufacturing networks) and assesses whether or not information sharing in such environments can reduce the potentially negative impact of uncertainty on accidents.

Design/methodology/approach – To assess the relationships between uncertainty, accidents and information sharing the authors utilise cross-country survey data collected through the sixth iteration of the International Manufacturing Strategy Survey. The authors conceptualise workplace accidents through production time lost due to accidents. Furthermore, the authors conduct multiple regression analyses to test the hypotheses.

Findings – Results suggest that procurement, production, and demand uncertainties do indeed lead to an increase in workplace accidents at the plant level. Furthermore, the negative impact of uncertainty can be significantly reduced through information sharing.

Originality/value – This study represents a comprehensive attempt to simultaneously assess the impact of uncertainty on workplace accidents at the plant level and the possible moderating impact of information sharing.

Keywords Survey, Workplace accidents, Social sustainability, Information sharing

Paper type Research paper

1. Introduction

In the past decade sustainability has become a strategic objective and performance dimension in the operations management domain alongside cost, quality, delivery and flexibility. Accordingly, there is a growing interest in exploring how sustainability aspects – workplace safety, environmental issues, diversity, and human rights – contribute to firm performance (Carter and Jennings, 2002, 2004; Carter, 2004, 2005). However, among the sustainability dimensions, workplace safety has received relatively little attention in the operations management domain (Lo *et al.*, 2014). Furthermore, Brown (1996) and Pagell *et al.* (2014) argue that amongst other operational dimensions safety should be treated as a key operational performance outcome, which in reality is neither reflected in the conceptualisation of sustainability research nor in practice (Lo *et al.*, 2014).

However workplace safety failures in terms of accidents do certainly have negative consequences for workers and may also result in catastrophic consequences for a firm's financial situation. They can provoke financial and productivity damages consisting of direct and indirect costs beyond the obvious loss of social consequences. Direct costs include workers' compensation payments, medical expenses, and costs for legal services. Important indirect costs include lost productivity and repairs to damaged property, which can impact the ability of the firm to meet customer demand.

Despite the manufacturing industry being one of the most dangerous in terms of frequency of workplace accidents (see, e.g. Eurostat, 2012), and USA (Bureau of Labor Statistics, 2012;

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Workplace Safety and Insurance Board, 2012a, b) it is still under-investigated in terms of safety issues (Cantor, 2008; Wiengarten *et al.*, 2017). In such a context, it is important to explore the drivers of workplace incidents and identifying ways to mitigate them. Our paper contributes through exploring this research gap by investigating the relationships between uncertainty, information sharing and workplace accidents.

Previous research on occupational safety and operations management has started to apply systematic theories of accidents such as normal accident theory (NAT) and high reliability theory (HRT) to analyse occupational safety concerns (Lo *et al.*, 2014). Proponents of NAT believe that accidents are inevitable to happen in complex and uncertain environments such as the shop floor or supply chain network (Perrow, 1984). HRT on the other hand proposes that if the system is highly reliable accidents can be avoided (Hovden *et al.*, 2010).

Due to the globalisation of the markets, the most notable trend in the manufacturing industry is that firms are organising their internal operations across multiple locations (Ferdows, 2008). However, such a setup requires careful coordination of physical and information flows. Over the last two decades, research on the structure and organisation of multinationals has shifted from a focus on the one-to-one headquarters-subsidiaries relationships towards a focus on managing a manufacturing network of units (Kogut, 1989; Choi and Kim, 2008). Specifically, in the case of manufacturing companies distributing internal operations activities between plants in different locations, the operations management literature has been referring to manufacturing networks (Ferdows, 2008; Vereecke *et al.*, 2006). Companies are faced with the challenge to manage these complex and dynamic networks, which brings its advantages and disadvantages (Choi and Krause, 2006).

Focussing on a firm's internal operations, the issue is no longer solely on where to locate plants but more so on how to manage the increased complexity and resulting uncertainties. Accordingly, recent economic developments resulting in globalisation and political and economic instability, changes to consumer preferences, increasing product variety, and shortening product life cycles have increased uncertainty for companies. Especially for those operating in multiple locations through manufacturing networks (Ferdows, 2008). Various forms of uncertainties have been identified to be negatively associated with operational performance. For example, the bullwhip phenomena stemming from a lack of information sharing, and thus uncertainties have been identified to negatively affect operational and financial performance (Forrester, 1958). However, what is known to a lesser extent is how uncertainty affects sustainability from a social perspective in terms of workplace safety and accidents. We believe that it has not been sufficiently explored how uncertainty relates to workplace accidents from an operations management perspective. Therefore, the objective of this study is to first test NAT to identify the impact of uncertainty on workplace accidents.

Furthermore, we analyse whether mitigation strategies can be implemented to reduce the negative effects of uncertainty. Previous research indicates that the hazardousness of these manufacturing worksites is derived from the fact that operators in each site often do not know what the other party in the network is doing. However, they are dependent on one another (Nenonen, 2011). Therefore, we suggest that in manufacturing networks that have control mechanisms in place and track and exchange information, organisations can mitigate workplace safety risks by reducing uncertainty. Indeed, a vast amount of literature on control mechanisms in manufacturing networks and supply chains suggests the fundamental role of information sharing to reduce uncertainty (Forrester, 1958; Croson and Donohue, 2003). We suggest that information sharing within manufacturing networks can reduce the negative impact of uncertainty and thus increasing the reliability of the system from a network perspective according to HRT. Thus, increasing the safety of the operations and supply chain, reducing accident rates.

Subsequently this research is set out to investigate the following research questions:

RQ1. To what extent does uncertainty affect workplace accidents?

RQ2. Can information sharing in manufacturing networks dampen the potential negative impact of uncertainty on workplace accidents?

Through exploring these research questions this paper contributes to the current discourse on social sustainability and workplace safety concerns in the operations and supply chain management field. Furthermore, we advance our knowledge about workplace accidents in plants operating in manufacturing networks.

Whilst we acknowledge that there has been a recent increase in research on the social aspects of sustainability (including worker's health and safety) in the operations management literature, we believe that it is still very much under represented and under explored, especially in comparison to recent research in environmental sustainability (Wiengarten *et al.*, 2017). Thus, the contribution of this paper is twofold: first, most studies on social aspects have the goal to investigate the relationship between economic and social aspects, implicitly considering the first one as being more important. Our paper explicitly focusses on social aspects and worker health and safety, as suggested by recent call for paper in the sustainable supply chain management literature (Montabon *et al.*, 2016). Second, the specific aspects and downsides of uncertainty have been extensively studied in the operations management community but not sufficiently from a safety perspective. This research explores these eminent research gaps.

Testing the research model through survey data the results indicate that uncertainty does indeed increase the rate of workplace accidents. Furthermore, in manufacturing networks characterised by high levels of information sharing companies can reduce this positive relationship. Thus, future studies might further investigate strategies to deal with uncertainty in relation to social aspects apart from operational outcomes. Additionally, this research will provide insights for operations managers dealing with global manufacturing networks that are characterised by uncertainty. Specifically, in multinational organisations operations managers deal with operational and safety issues in manufacturing plants that are located in different parts of the world but are interdependent. What is done in each of these plants might influence each other performance. The impact of this interconnection on social performance is often under estimated, thus causing workplace accidents and negative reputational impacts. We provide evidence for practitioners that plants in a manufacturing network are interconnected and uncertainty in this network might damage social performance. Information sharing is proposed as a tool to face such uncertainty and reduce workplace accidents in the nodes of this network.

2. Literature review

Increasing competition and globalisation have driven improvements in operations systems of manufacturing companies. These improvements range from the adoption of lean production systems reducing production cost, waste and increasing flexibility (Womack *et al.*, 1990; White *et al.*, 1999; Shah and Ward, 2003) to operations activities in supply chains to take advantages of inputs in different locations, increase production capacity and cost efficiencies (Vereecke *et al.*, 2006). It remains the case, however, that the manufacturing industry is one of the most dangerous sectors for workers, given the frequency and severity of workplace accidents (Cantor, 2008; Silvestri *et al.*, 2012).

Recent studies started to answer to the call of operations management scholars to study occupational health and safety issues (e.g. Pagell and Shevchenko, 2014), which recently was rather neglected in our research field. Specifically, most of the previous research in our field focussed on the investigation of lean manufacturing being either safe or unsafe (e.g. Hasle *et al.*, 2012; Longoni *et al.*, 2013; Longoni and Cagliano, 2015). Researchers in other fields, such as occupational safety and industrial relations, have more thoroughly examined the impact of lean on workplace safety often blaming lean manufacturing, highlighting its possible negative implications (Brännmark and Håkansson, 2012). More generally, the safety literature suggests that lean manufacturing, reducing cycle time and buffers in the system, may increase workloads and work intensity and hence increase worker effort and stress. And these can have negative implications for workplace safety (Landsbergis *et al.*, 1999; Askenazy, 2001). However, recent advances in the operations management literature showed that these possible negative effects can be mitigated through complementary practices such as human resource management practices allowing workers to be prepared to face the more demanding activities in lean manufacturing systems (Longoni *et al.,* 2013).

In our study, focussing on NAT, we concentrate on another source of stressful working conditions, and possibly a source of workplace safety risks, characterising the current manufacturing context; namely uncertainty. Accordingly, uncertainty may result in stressful situations such as work overload or underload, shift work, long hours, and changes in the work schedule that determine workplace accidents (Lo *et al.,* 2014). Uncertainty can be defined as the inability to assign probabilities to future events (Duncan, 1972) or the difficulty to accurately predict the outcomes of decisions (Duncan, 1972; Downey *et al.*, 1975).

In this paper, we focus on uncertainty stemming from procurement, production and demand activities (Davis, 1993). We propose that this type of uncertainty could be related to workplace safety especially for companies operating in manufacturing networks.

2.1 The impact of uncertainty on workplace accidents

Previous research in operations and supply chain management has, to a great extent, explored the negative impact of uncertainty on the efficiency of manufacturing processes (e.g. Mapes *et al.,* 2000). Uncertainty can enter the production systems from multiple dimensions such as the procurement side – when and how many supplies will be delivered, production – how much will be produced, and demand side – how much customers demand (Davis, 1993). These types of uncertainty have been linked to low levels of asset utilisation, and an increase in inventory and forecasting error. Therefore, from an operations performance objective uncertainty can lead to increased costs, lead times and quality concerns. Thus uncertainty may determine scheduling pressures and result in inadequate time for performing operational activities and subsequently putting workers in stressful conditions (Crum and Morrow, 2002; Grosse *et al.,* 2015; Moatari-Kazerouni *et al.,* 2015), fatigue peaks and increase uncertainties of the tasks at hand (Brown, 1996). These aspects may be particularly relevant for companies operating in manufacturing networks. In such networks, entities are often interdependent and managing and coordinating activities could be extremely complicated under uncertain conditions (Ferdows, 2008). The consequence could be that simultaneous work tasks or upcoming tasks are not known to all parties involved in the manufacturing network. Therefore, workers in each site need to react fast to changes in the system increasing workers stress and fatigues and so increasing the risk of workplace accidents.

NAT proposes that accidents are inevitable in working systems that are complex, tightly coupled and have catastrophic potential (Perrow, 1981, 1984). In complex systems small malfunctions that are seemingly unrelated can accumulate and result in potentially major disruptions to the system. The manufacturing environment has been identified as inhibiting the aforementioned three types of uncertainty (i.e. procurement uncertainty, production uncertainty, and demand uncertainty) and thus as a factor that increases complexity (Lo *et al.,* 2014). Whilst procurement, production and demand uncertainty are interrelated they may accumulate and align to create disruptions at the network level, which may result in accidents.

Uncertainty or an increase in uncertainty might therefore increase the likelihood of workplace accidents. Uncertainty may lead to more complex processes as the planning horizon is shortened or in some cases non-existence. For example, process orders might have to be changed on an ad-hoc basis because of order or processing changes. This may lead to less time to prepare or train the workforce for these changes. The workforce may also be required to perform certain tasks at an increased speed, which may lead to role overload and an increased likelihood of accidents (Lo *et al.,* 2014). Based on the reviewed literature and NAT an increase in uncertainty might lead to an increase in accidents. Subsequently, we propose:

H1. Uncertainty is positively related to workplace accidents.

2.2 The role of information sharing on the uncertainty – workplace accidents relationship

HRT researchers claim to counter the arguments made by NAT (LaPorte and Consolini, 1991). HRT proposes that accidents are avoidable that can be reduced through making the working environment more reliable and thus managing complexity in working systems. Specifically, HRT proposes to manage and reduce complexity which leads to accidents through: continuous training; the use of redundancy; and information exchange (Hovden *et al.,* 2010). In this paper we explore the aforementioned third option, information exchange.

Lo *et al.* (2014) tested the impact of OHSAS 18001 certification (i.e. an external certified occupational health and safety system) on operating performance taking into consideration complexity and coupling. The complexity variable is approximated through R&D intensity and labour intensity, which is related to uncertainty. They identified that OHSAS certification is more efficient in complex environments. OHSAS certification, which to some extent formalises and standardises environmental management efforts, helps to improve safety performance. Furthermore, this effect increases with the level of complexity, which is strongly correlated to uncertainty. In building on NAT and HRT they developed the case that OHSAS certification provides an approach to reduce complexity and increase the reliability of the working environment.

However, there are multiple ways through which reliability can be increased, such as process or machine standardisation or increased control. Focussing on the latter, increasing control has been often suggested as a strategy to reduce risks in supply chain management (Jüttner *et al.,* 2003; Kleindorfer and Saad, 2005) and thus could also have a crucial role in relation to workplace safety. Control can be achieved predominately through vertical integration. In an ideal state, all operational activities are managed in a single unit and location (Bagchi *et al.,* 2005). However, vertical integration increases fixed costs and reduces flexibility. Due to increasing competition, globalisation and sophistication of customer demand, there is a growing trend towards the adoption of conducting operational activities in different location through manufacturing networks (Ferdows, 2008). In these fragmented and dispersed networks, firms are looking for the benefits of control, adopting more integrated and holistic ways to manage their network. Among the different possible strategies to integrate and manage a manufacturing network holistically, previous research has consistently stressed the importance of information sharing, which results in higher levels of network integration (Flynn and Flynn, 1999; Flynn *et al.,* 2010; Wong *et al.,* 2011). Accordingly, in manufacturing networks characterised by high levels of information sharing, uncertainty can be reduced. Taking the supply chain as an example, in essence the bullwhip effect is about uncertainty of demand, supply and inventory levels. It has been identified that information sharing through process integration is a major remedy to dampen the bullwhip effect. Forrester (1958) argues that order behaviour in a system is a function of the interaction of structure (effective organisation structure and information sources), delays (time between cause and effect/decision and implementation, etc.), and amplification (the inherent effects of policies). Thus, information must be reliable and timely (Forrester, 1958). Information sharing among the parties of a system and tightly integrated processes can therefore reduce certain levels of complexity and uncertainty (Lee *et al.*, 1997).

Therefore, information sharing leads to more accurate planning in terms of scheduling and inventory management. Production managers as well as shop floor workers can plan in advance and thus uncertainty and complexity is reduced. Through information sharing workers know what other parties in the network are doing and reduce the uncertainty in the system and the risk of workplace accidents. The reduction of uncertainty increases the planning horizon and security for the workforce (Grosse *et al.*, 2015). This reduces stressful and unexpected situations, which could have resulted in work overload, rushing orders through and eventually in workplace accidents. Thus, based on these arguments we propose the following hypothesis:

H2. The positive relationship between uncertainty and workplace accidents is reduced in manufacturing network characterised by relatively high levels of information sharing.

3. Research methodology

3.1 Sample

To explore our research questions:

RQ1. To what extent does uncertainty affect workplace accidents?

RQ2. Can information sharing in manufacturing networks dampen the potential negative impact of uncertainty on workplace accidents?

We utilised data collected through the International Manufacturing Strategy Survey (IMSS). The IMSS is a global network of researchers that collaborate with each other and manufacturing companies to develop a common survey to study current issues and trends in global manufacturing and supply chain management (Wiengarten *et al.*, 2014). The data used in this study were collected in 2013 between June and September and is part of the sixth iteration of the survey. The target respondent was the plant, production or operations manager. The respondent was contacted first via phone, if the respondent showed some interest in participating in the research, the questionnaire was sent to him/her by e-mail or sending a link to an online platform. The response rate after this initial first contact was 13 per cent for the whole sample across countries. After some weeks, reminders were sent if no feedback was received. Returned questionnaires were controlled for missing data and were handled on a case-by-case basis, usually by contacting the company again. The final response rate after multiple reminders was 36 per cent for the whole sample across countries.

Companies were stemming from multiple manufacturing industries across a wide array of countries (see Table I). The majority of companies were medium sized (169 companies with 51-250 employees, 157 companies with 251-100 employees) to large (150 companies with more than 1,001 employees). However, some small companies were also present in our sample (1 company with 1-10 employees, 8 companies with 11-50 employees).

We then tested for response bias through comparing late with early respondents through company size and industry. Results indicate that early respondents do not significantly differ from late respondents in terms of size and industry.

We selected only a subset of companies from the IMSS sample. Specifically, we needed to select companies that are part of a manufacturing network in order to test our second hypotheses. However, we also tested our first hypothesis also with the full data set. And the results did not deviate significantly from the presented results. Subsequently, we continued using the same truncated sample for both hypotheses.

Table I. Sample overview

	Frequency
Industry	
Manufacturer of fabricated metal products, except machinery and equipment	148
Manufacturer of computer, electronic and optical products	57
Manufacturer of electrical equipment	87
Manufacturer of machinery and equipment not elsewhere classified	109
Manufacturer of motor vehicles, trailers and semi-trailers	60
Manufacturer of other transport equipment	24
Total	485
Country	
Belgium	20
Brazil	21
Canada	13
China	48
Denmark	21
Finland	12
Germany	9
Hungary	31
India	34
Italy	27
Japan	57
Malaysia	9
The Netherlands	27
Norway	22
Portugal	23
Romania	16
Slovenia	10
Spain	19
Sweden	25
Switzerland	16
Taiwan	2
USA	23
Total	485

3.2 Measures

This study focusses on exploring the impact of uncertainty on workplace accidents and information sharing. Previous literature has measured uncertainty through multiple dimensions entering different activities (i.e. procurement, product, and demand) and at multiple levels (e.g. plant level, supply chain network level, industry level, country level). In this study we focus on the impact of uncertainty at the plant level from a procurement, production, and demand perspective (Davis, 1993). Specifically, uncertainty was measured through prompting respondents to indicate three items (on a scale of one to five) the extent to which they agree that: your demand fluctuates drastically from week to week; your total manufacturing volume fluctuates drastically from week to week; and your supply requirements (volume and mix) vary drastically from week to week.

Furthermore, we follow previous research in assessing accidents through measuring the percentage of production time lost due to serious accidents at the plant level (Margolis, 2010). Information sharing in the manufacturing network environment was measured through prompting the respondents to indicate the current level of implementation related to improving information sharing for the coordination of the flow of goods between their plant and other plants of the network (e.g. through exchange information on inventories, deliveries, production plants, etc.) on a five-point scale (e.g. Wiengarten and Longoni, 2015). All items are listed in Table II including their descriptive statistics.

Table II. Survey items and confirmatory factor analysis results

Variables/Items	Mean	SD	Loading stand.	SE	R^2
Uncertainty	2.64	0.971			
Your demand fluctuates drastically from week to week			0.86	0.031	0.71
Your total manufacturing volume fluctuates drastically from week to week			0.87	0.026	0.74
Your supply requirements (volume and mix) vary drastically from week to week			0.80	0.029	0.59
Information sharing	3.26	1.017			
Improve information sharing for the coordination of the flow of goods between your plant and other plants of the network (e.g. through exchange information on inventories, deliveries, production plants, etc.)					
Workplace accidents	1.48	4.30			
Rate of production time lost for serious accidents (%)					
Health and safety programs					
Formal occupational health and safety management system					
Manufacturing network type					
Domestic, Regional, Global					

Furthermore, we controlled for multiple factors that may have a confounding influence on our results. Through introducing them in our analyses we increase the generalisability of our results. Specifically we controlled for size (i.e. number of employees), information sharing in the manufacturing network environment (for the first hypothesis), health and safety programs (i.e. improvement efforts in health and safety conditions), and manufacturing network type in terms of dispersion (i.e. domestic, regional or global) to test *H1*.

3.3 Reliability and validity

We conducted confirmatory factor analysis (CFA) in LISREL 8.80 to validate our uncertainty measures and thus to confirm our proposed factor structure. In the following, we analyse and discuss various dimensions of validity and reliability (Nunnally, 1978; Anderson and Gerbing, 1988). First, we believe that content validity is present because of the several iterative stages that the IMSS survey has been conducted. Furthermore, multiple researchers have been involved and continuously improved the content validity of the applied measures. Additionally, through the CFA results we tested for convergent validity (O'Leary-Kelly and Vokurka, 1998). Our proposed structure of the items measuring uncertainty resulted in a reasonably good fitting model (GFI = 0.89; standardised RMR = 0.23; IFI = 1; NFI = 1) indicating convergent validity. Additionally, all factor loadings exceeded the value of 0.50 (see Table II) and the standardised factor loadings all exceeded twice the value of their associated standard error, which confirms convergent validity (Flynn *et al.*, 2010).

Finally, the Cronbach's α value for uncertainty is 0.863, which indicates that reliability is relatively high (Table III).

4. Results

To test our hypotheses, we conducted OLS regression analysis in *SPSS 20*. OLS regression is a generalised linear modelling technique that can be used to model single response variables, which have been recorded on at least an interval scale. Furthermore, it can be applied to single or multiple explanatory variables (i.e. uncertainty and control variables) and also categorical explanatory variables (Hutcheson, 2011).

Table IV summarises the results for *H1*. For our first hypotheses, whether or not uncertainty increases workplace accidents at the plant level, the regression model was

Correlations	(1)	(2)	(3)	(4)	(5)	(6)
Size (1)	1					
Information sharing (2)	0.095*	1				
Health and safety programs (3)	0.034	0.191**	1			
Manufacturing network type (4)	0.092*	−0.036	0.070	1		
Uncertainty (5)	−0.058	−0.037	0.055	−0.025	1	
Production time lost (6)	−0.023	0.028	−0.137**	−0.159**	0.119**	1

Notes: *,**Correlation is significant at the 0.05 and 0.01 levels (two-tailed)

Table III. Correlation table

Variables	Standard β coefficient	*t*-value	Sig	VIF
Control				
Size	−0.006	−0.120	0.904	1.021
Information sharing	0.056	1.194	0.233	1.052
Health and safety programs	−0.147	−3.157	0.002	1.053
Manufacturing network type	−0.139	−3.025	0.003	1.021
Independent variable				
Uncertainty	0.129	2.825	0.005	1.014
R^2		0.060		
SE of the estimate		4.307		

Table IV. Production time lost: regression results

specified as follows: $Y = \beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 x_i + \varepsilon_i$. ($Y =$ production time lost, $\beta_1 =$ size, $\beta_2 =$ information sharing, $\beta_3 =$ health and safety programs, $\beta_4 =$ manufacturing network type, and $\beta_5 =$ uncertainty).

Before carrying out the OLS analysis, the data were tested for linearity, equality and multicollinearity (Kennedy, 1999). We tested for linearity and the equality of variance, which is a pre-requisite for regression, through plotting standardised residuals against the standardised predicted values. The plotted figure confirmed the linearity and equality. Furthermore, since some of our variables show relatively high levels of correlations (see Table III), the likelihood of multicollinearity is reasonably high (Aiken and West, 1991). Thus, we calculated the variance inflation factors (VIFs) to further detect any possible threats. Results indicate that all VIF values are all close to 1, which indicates that multicollinaearity seems to be less problematic in this analysis. Furthermore, we calculated the Belsley-Kuh-Welsch indices and confirmed that multicollinearity does not seem to impose a significant threat to our analysis (Belsley *et al.*, 1980).

Results indicate that after controlling for size, information sharing, health and safety programs, and manufacturing network type in the first step, uncertainty, entered in the second step, has a positive impact on workplace accident rates. Specifically, out of the four control variables, size ($b = -0.006$; $p = 0.904$) and information sharing ($b = 0.056$; $p = 0.233$) are not significantly related to workplace accidents whilst health and safety programs ($b = -0.147$; $p = 0.002$) and manufacturing network type ($b = -0.139$; $p = 0.003$) do have a significant impact. However, whilst controlling for these four factors our results indicate that an increase in uncertainty results in an increase in lost production time due to accidents ($b = 0.129$; $p = 0.005$). The proposed model results in an r-square of 0.060 ($F = 5.836$). Thus, these results confirm our first hypothesis.

In our second hypothesis we propose that the positive impact of uncertainty on workplace accidents can be reduced in contexts characterised by high levels of information sharing within the manufacturing network. According to Venkatraman (1989), two approaches can be used to test a moderation relationship: testing for interaction effects and by analysing sub-groups. The interaction effect approach is used to test moderation effects, if the performance outcome is jointly determined by the interaction of the predictor and the moderator. On the other hand the subgroup approach is more appropriate when the moderation effect refers to the fact that the predictive ability of certain independent variables differs across different environments. *H2* suggests that uncertainty has varying impacts on workplace accidents according to how the environment is characterised in terms of the adoption of information sharing practices (i.e. a relationship that should be tested using subgroup analysis). Thus, we tested *H2* by splitting the sample into two groups. Group one represents companies with low levels of information sharing ($n = 268$) in their manufacturing network (i.e. 1, 2, and 3 on the Likert scale) and group two represents companies with high levels of information sharing ($n = 217$) in their network (i.e. 4 and 5 on the Likert scale). We chose to categorise the levels of information sharing based on the five-point Likert scale and the natural divide of the sample into these comparable sample sizes of the two groups.

Results presented in Tables V and VI indicate that our second hypothesis is also supported. In Table V the results of the impact of uncertainty on workplace accidents are presented under the condition of low levels of information sharing ($R^2 = 0.098$). Results indicate that the impact of uncertainty on workplace accidents at the plant level is significant when companies only practice low levels of information sharing in their manufacturing network ($b = 0.139$; $p = 0.020$).

Furthermore, in Table VI we present the results of the impact of uncertainty on workplace accident under the condition of high levels of information sharing ($R^2 = 0.029$). In this scenario the results indicate that the impact of uncertainty on workplace accident is

Table V.
Regression results: Low levels of information sharing setting

Variables	Standard β coefficient	*t*-value	Sig	VIF
Control				
Size	0.010	0.168	0.867	1.026
Health and safety programs	−0.147	−2.441	0.015	1.059
Manufacturing network type	−0.183	−3.033	0.003	1.053
Independent variable				
Uncertainty	0.139	2.349	0.020	1.018
R^2		0.098		
SE of the estimate		5.040		

Note: $n = 268$

Table VI.
Regression results: High levels of information sharing setting

Variables	Standard β coefficient	*t*-value	Sig	VIF
Control				
Size	−0.030	0.896	0.371	1.013
Health and safety programs	−0.114	−1.576	0.117	1.018
Manufacturing network type	−0.045	−0.618	0.537	1.027
Independent variable				
Uncertainty	0.115	1.576	0.117	1.033
R^2		0.029		
SE of the estimate		2.894		

Note: $n = 217$

insignificant ($b = 0.115$; $p = 0.117$) when companies practices high levels of information sharing in their manufacturing network. Thus, in conclusion these results provide empirical support for our second hypothesis.

5. Discussion

This paper applied the theoretical lenses of the NAT and HRT to explore the following research questions:

RQ1. To what extent does uncertainty affect workplace accidents?

RQ2. Can information sharing in manufacturing networks dampen the potential negative impact of uncertainty on workplace accidents?

We explored these research questions focussing on the manufacturing context. We believe that this is an appropriate setting for our research because the manufacturing context is especially affected by workplace accidents and uncertainty (Cantor, 2008; Moatari-Kazerouni *et al.,* 2015). Specifically, manufacturing networks are becoming a growing reality and managers are encountering several challenges to manage them (Ferdows, 2008). In such a context, we found that uncertainty on the procurement, production, and demand sides are positively related to workplace accidents at the plant level, thus having a negative effect on workplace safety and social performance. Furthermore, we show that manufacturing networks characterised by high levels of information sharing can mitigate uncertainty and thus reduce workplace accidents at the plant level. These results have important implications for theory and practice, which we discuss in the following subsections.

5.1 Theoretical implications

Our research provides implications for the occupational safety and operations and supply chain management literatures building on the NAT and HRT. Furthermore, building on these theories we contribute to a growing body of research that acknowledges the increasing complexity of managing manufacturing networks and the crucial role of uncertainty (Vereecke *et al.,* 2006; Ferdows, 2008).

Specifically we proposed and confirmed, based on the NAT, that uncertainty is a driver of workplace accidents at the plant level. In doing so, we extent previous operations and supply chain management literature acknowledging the negative impact of uncertainty on operational and financial performance but not considering workplace safety and social implications (Wong *et al.,* 2011). We also contribute to the recent debate in the operations and supply chain research field focussing on worker safety and social sustainability (Pagell and Shevchenko, 2014; Montabon *et al.,* 2016). This recent research stream sheds new light into the upcoming debate on worker safety in operations management and about the impact of operations paradigms and practices, such as lean manufacturing, on operational and safety performance (Hasle *et al.,* 2012; Longoni *et al.,* 2013). However contributions considering contextual aspects (e.g. uncertainty), and network characteristics (e.g. information sharing) have, so far, been rather neglected. Therefore, we advance our knowledge on the role of uncertainty on performance in the operations systems taking a more current perspective considering the impact of uncertainty on sustainability focussing specifically on the social dimension and on workplace safety. Our results align with the NAT perspective. NAT suggests that accidents are inevitable to happen in complex and uncertain environments such as the shop floor (Perrow, 1981, 1984). An increase in uncertainty contributes to this complexity. High levels of demand, supply and production uncertainty make it difficult to schedule, plan and control capacity. This lack of planning accuracy and ability directly affect the workforce on the shop floor. Any disruption or spike in demand has to be met with a quick ability to eventually ramp up the production volume and capacity. This is commonly accompanied by work overload, stress and workforce jeopardising their safety in order to achieve this flexibility. Our results indicate that in many cases this results in workplace accidents.

However, our results also align with the predication of HRT. Results also indicate that companies can manage this uncertainty, and increase reliability, through focussing on information sharing in the manufacturing network. Thus showing the role that information sharing could play as a mitigation strategy to reduce the positive relationship between uncertainty and workplace accidents. The role of information sharing to manage uncertainty has been confirmed at length in relation to the traditional operational performance dimensions (Flynn and Flynn, 1999; Flynn *et al.*, 2010) and in relation to supply chain uncertainty in general (Wong *et al.*, 2011). We further develop this stream of research by showing its effects on the uncertainty-workplace safety relationship.

The HRT provided an interesting lens to identify possible moderators of the uncertainty-workplace accidents relationship. HRT suggests that in reliable environments the risk of workplace accidents are reduced (Lo *et al.*, 2014). Previous research has started to explore practices that increase reliability as such. Lo *et al.* (2014) identified that through OHSAS 18001 companies can reduce complexity and reduce accident rates. We confirm the theoretical arguments of the HRT and identified that information sharing within a network as a strategic practice can increase system reliability through increased control over the system and the activities performed by the different entities. It is important to note that information sharing, besides other benefits, can reduce network complexity and reduce the level of workplace accidents. Therefore, we contribute to the supply chain integration literature identifying this additional safety benefit of sharing information in complex manufacturing networks. Additionally, providing evidence of the link between uncertainty and safety issues, we propose future studies to further investigate the functioning of manufacturing networks and their implications specifically on social performance, answering to the calls for more studies focussing on social and environmental sustainability and not considering them as subordinated economic and operational outcomes (Pagell and Shevchenko, 2014; Montabon *et al.*, 2016).

5.2 Managerial implications

The findings verify that procurement, production and demand uncertainty is a predictor of workplace safety at the plant level. The empirical evidence provides relevant references for senior managers of manufacturing firms in contexts characterised by high uncertainty embedded in manufacturing networks and also impacting on the societies in which they are embedded in. Our results suggest that managers can expect that workplace accidents are more likely to occur in plants with a higher rate of uncertainty as compared to a more certain and stable context. This may lead to catastrophic events in the system ranging from negative social impacts to economics impact due to the interruption of the production and the costs supported to overcome the social impacts, missed deliveries and to recover to the negative consequences in the system.

Not only does our study show the impact of uncertainty on workplace safety but we also provide evidence of the benefits of information sharing at the network level as a possible mitigation strategy reducing the negative impact of uncertainty on workplace safety. We thus provide managers with a managerial tool to mitigate uncertainty to reduce its negative impact on social performance. Confirming the link between plant performance and network characteristics is extremely relevant in today's manufacturing context characterised by multinational companies operating in complex and uncertain manufacturing networks. Today, stakeholders are demanding companies to manage their operations not only from a financial point of view but with a broader perspective taking into account environmental and especially social implications (Pagell and Shevchenko, 2014). Preventing workplace accidents is fundamental to operations and supply chain managers to ensure occupational health and safety and to assure the sustainability of their companies. Additionally, reducing workplace accident risks means also having a positive impact on the societies in which the companies are embedded, preserving workers health and safety and improving working conditions.

6. Conclusion

Operations and supply chain management academics and practitioners attention towards social performance and workplace safety has been low (see Hasle *et al.,* 2012 for a review). However, whilst a recent increase in publications about the implication of certain aspects of operation and supply chain management on workplace safety could be detected it is still largely underexplored (Wiengarten *et al.,* 2017).

This research contributes to this growing stream of research on workplace safety by taking into account recent trends such as characterising manufacturing activities as networks and the inhibit increasing uncertainty characterising the external environment impacting on such a system. Specifically, by firmly grounding this research in the NAT and HRT, we show that uncertainty can be a source of workplace accidents in firms operating through manufacturing networks due to its negative impact on task scheduling, increased pressures and stressful working conditions. Further, we demonstrate that manufacturing networks characterised by high levels of information sharing may help to make the system more reliable and thus negatively moderates the positive relationship between uncertainty and workplace accidents.

Although this research makes significant contributions to the academic literature and provides important managerial implications, our study suffers from certain limitations that need to be taken into consideration when interpreting our results that provide opportunities for future research. First our study focussed solely on the uncertainty element while NAT suggests that also complexity in the system may be a source of workplace safety risks. Thus future research could investigate how complexity, as the number of entities in the system, their location and their interdependences could influence workplace safety. The relative roles of uncertainty and complexity could be investigated. Second, we did not explore the influence of industry differences on the uncertainty-accidents relationship. In certain industries uncertainties may differ due to the characteristics of the production process and of the supply and customer markets. Future research may include this dimension in their analysis. Finally, we did not investigate uncertainties external to the system such as disruption risks or external conditions influencing the functioning of the firm's operations. Future studies may investigate such aspects to complement our current research and results and demonstrate if information sharing could mitigate also the effects of this different type of uncertainties on workplace safety.

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