Managing Risk for Auto Warranties

Abstract

Purpose - This paper aims to (1) analyse the existing work of warranty risk management (WaRM); (2) develop a generic WaRM framework; and (3) design a generic taxonomy for warranty hazards from a warranty chain perspective.

Design/methodology/approach – To understand the top warranty hazards, we designed a questionnaire, received 40 responses from the warranty decision makers (WDM) in the automotive industry in the UK and then analysed the responses.

Findings – The assembly process capability at suppliers is the top contributor to warranty incidents from the suppliers' and original equipment manufacturers (OEMs') viewpoints. The human error at different stages of the product lifecycle contributes to the occurrence of warranty incidents. The collaboration among parties, particularly, the accessibility to warranty-related data between parties (i.e., suppliers, OEM and dealers), is limited. Customers' fraud contributes more to warranty costs than warranty services providers' (WSPs) fraud. The top contributors to customer dissatisfaction relating to warranty are the warranty service time and service quality.

Research limitations/implications – The questionnaires were used to collect data in the UK, which implies the research outcomes of this paper may only reflect the UK area.

Practical implications – The WaRM framework and taxonomy proposed in this paper provide warranty decision makers with a holistic view to identifying the top contributors to warranty incidents. With them, the decision makers will be able to allocate the required fund and efforts more effectively.

Originality/value – This paper contributes to the literature by providing the first work of systematically analysing the top contributors to warranty incidents and costs and by providing a WaRM framework.

Key Words*:* Warranty; risk management; hazard identification; social media; warranty chain; human error.

Article Classification: research paper

1 Introduction

Manufacturers may offer competitive warranty packages to their customers to retain or increase their market shares. However, offering warranty also brings various risks that can have an enormous impact on manufacturers' profits and reputation. For instance, Ford and GM, usually spend $3 and $4 billion on warranty claims per year, respectively (WarrantyWeek, 2015). Toyota and Honda paid 605 billion Japanese yen[1] and 341 billion Japanese yen on warranty claims between 2003 and 2017, respectively (WarrantyWeek, 2017).

The importance of warranty goes beyond manufacturers and customers as it can be seen from the fact that many governmental bodies impose regulations to resolve any potential dispute. For example, in the United States, the Magnusson-Moss Warranty Act was passed by Congress. In the European Union, new legislation requires manufacturers to offer a two-year warranty on all new products (Murthy & Djamaludin, 2002).

[1] The Japanese yen against dollar exchange rate has fluctuated between 82 and 120 yen to the dollar over the past fifteen years.

Although warranty management has increasingly become important, little research has systematically studied warranty risks. This creates an imperative in research and is the purpose of this paper. Due to the discrepancy existing in warranty risk management (WaRM) in different industries, this paper focuses its attention on the automotive industry.

1.1 Related Work

In the literature, WaRM has not been systematically studied in any publication and has only been mentioned as a side topic by some work. For example, Díaz & Márquez (2011) investigate the problem with efficiency in the warranty programme and proposed a warranty management framework including generic tools developed for project management such as cost-risk-benefit analysis. Costantino et al. (2012) analyse customers' perceptions regarding products, warranty service, and related risks. González-Prida & Márquez (2012) proposed a warranty management framework outlining the main aspects that should be considered to achieve the warranty plan and obtain customers' satisfaction accurately.

Additionally, the literature discussed some technical and commercial aspects, as explained in the following, which may lead to warranty incidents or influencing customers' satisfaction.

- Technical aspect, which is mainly on the reliability and quality related issues. Kozlovskiy et al. (2016) propose models to assess and monitor different quality criteria in the automotive industry. Michael et al. (2017) develop an approach to improving the quality of product validation that helps reduce warranty claims and recalls. Motabar et al. (2018) investigate how the poor reliability can affect warranty cost by reviewing the powertrain warranty. Makarova et al. (2019) investigate the importance of warranty services and suggest that preventive maintenance is needed.
- Commercial aspect, which is mainly on the role of warranty policy and the provision of warranty services related issues on the product demand and customers' satisfaction (Alqahtani & Gupta, 2017). Sun & Wu (2016) investigate the effect of a new government regulation imposed on product warranties, and its implications on the product demand. Sabbagh et al. (2017) find that the high-quality service and warranty length increase the demand on the product, although the quality of the product quality may be low. Borchardt et al. (2018) and Famiyeh et al. (2018) conclude that the quality of warranty services may have a direct impact on the customers' satisfaction and loyalties.

To efficiently identify warranty hazards is the cornerstone step in WaRM. Murthy & Blischke (2000) highlighted the importance of considering warranty risk related issues from the strategic level. Warranty hazards are discussed in some publications. For example, Wu (2012) listed some hazards of warranty claims and categorised them into four groups: (1) hardware failures; (2) software failures; (3) human errors, and (4) organisational errors. Wang et al. (2017) consider the impact of customers' behaviours such as failed-but-not-reported (FBNR) events in a forecasting model. Luo & Wu (2018) consider a set of warranty hazards in warranty policy optimisation.

However, to our best knowledge, little research has been systematically concentrated on WaRM, which creates the need for this work.

1.2 Novelty and Contribution

On the existing research, we have the following comments.

- Although the existing publications have partly discussed warranty-related hazards, WaRM has not been systematically studied.
- Although the role of human error has been discussed in warranty claim (see Wu (2011), for example), it has not been investigated from the perspectives of different players such as original equipment manufacturer (OEM), suppliers, warranty service providers (WSPs) and customers, respectively.

As such, this paper focuses on answering the above questions and makes the following contributions.

- It is the first work that systematically analyses WaRM and develops a generic WaRM framework.
- Warranty hazards are analysed from a warranty chain perspective.
- A generic warranty hazard taxonomy is developed.

A questionnaire for understanding WaRM was designed and circulated among WDM in the UK automotive industry. 40 responses were received and analysed.

1.3 Overview

The remainder of this paper is structured as follows. Section 2 discusses a questionnaire designed for WaRM for the automotive industry and then analyses the responses. Section 3 proposes a new WaRM framework . Section 4 discusses the taxonomy of warranty hazards. Section 5 concludes the paper.

2 Questionnaire design and analysis

In this section, a questionnaire is designed for understanding warranty risks in the automotive industry in the UK. The findings of this section may also provide a useful guide to other industries.

A questionnaire of 31 questions was designed to obtain a better understanding of the existing WaRM methods used in practice in the automotive industry in the UK. These questions are divided into five blocks, as listed below.

1) Respondents and their organisations' information. The organisations include OEMs, suppliers and dealers. This block is designed to understand the background of the questionnaire respondents.
2) Warranty-related information. The purpose of this block is to understand the average warranty length and costs.
3) Risk analysis tools. This block asks the existing tools used to identify, assess and mitigate warranty risks and their limitations.
4) The contributors to warranty incidents are from two perspectives: the product lifecycle and warranty chain perspectives.
5) The role of human error in warranty risk. Human error has been mentioned in some studies as a source of warranty claims. This block was designed to understand who the main contributors are.

The questionnaire was then distributed by www.qualtrics.com[2] to the suppliers, OEMs and dealers in the UK in Feb 2018. The distributed questionnaire covered the main carmakers in the UK and their suppliers and dealers. 300 questionnaires were distributed. 116 questionnaires were received. For analysis the responses, we then selected 40 respondents (including 20 dealers, 15 suppliers and 5 OEMs), which passed the data quality validation.

The questionnaire was mainly designed based on two types of questions. The first one is closed-ended questions including Likert-type scales (Likert, 1932), stars rating, multiple choice questions and firmographic questions. The second type is open-ended questions, which allow respondents to add their own comments if needed.

2.1 Questionnaires and Data Analysis

Most of the questions were designed based on a Likert-type scale (1-5). In the following tables, the percentages of the responses to the questions in the questionnaire are presented, which will allow

[2] www.qualtrics.com is the world's first experience management platform. Its core business is to gather business data for clients and used for academic research and market research.

the reader to perform further analysis. To ease analysing such data and reporting the results, we will group the responses into three main types: (1) agree (including *Very likely* and *likely* choices), (2) disagree (including *Unlikely* and *Very unlikely* choices), and (3) neutral (including *Equally likely*).

2.1.1 Identification of Warranty Hazards and Risk Assessment Tools

There are several questions on the existing tools used to identify warranty hazards and assess the associated risks.

To gain a better understanding of the existing tools used to identify warranty hazards, the respondents were asked, *"Which tools are used by your organisation to identify warranty hazards?"* The first two columns in Table 1 show the most common tools used by their organisations and the proportions of the corresponding tools, respectively. The root-cause analysis technique, checklist analysis and information gathering are the top tools used to identify warranty hazards with 16%, 15% and 14.90%, respectively. In contrast, the assumption list technique is not often used (5.12%).

Table 1: Tools used to identify warranty hazard

Identification Tool	Percentage (%)	**Risk Assessment Tool**		Percentage (%)
Checklist analysis	15. 00	Failure tree analysis		15.00
Information gathering	14.90	FMEA		29.04
Assumption list	5.12	FMECA		39.88
Brainstorming	7.85	Delphi technique		14.62
Interview	9.86	Other		1.40
Delphi technique	7.22			
Root cause analysis	16.00			
Documentation review	9.61			
SWOT analysis	14.25			

About the warranty risk assessment, the respondents were asked about the existing tool(s) used to assess warranty risks. The last two columns in Table 1 show that the most common tools used in warranty hazard assessment and the proportions of the corresponding techniques, respectively. The failure mode effect and criticality analysis (FMECA) (39.88%), followed by failure mode and effect analysis (FMEA) (29.04%) are the top two tools used.

Respondents were also asked, *"What are the limitations of the existing tool(s) used to assess warranty risks?"* They stated different limitations. For example, they stated that *"it requires human interaction"*, *"risks tend not to be known until an incident has happened on a recurring basis, and the tools do not always identify this as a risk", "accuracy of the data", "time it takes for them to be processed, time it takes to access tools, time it takes for money to be provided for the relevant work from the supplier/OEM" and "limited time*". These responses suggest that tools need improving to identify hazards systematically and a concern is the time problem.

Once the warranty risks have occurred, they may have different impacts. As such, respondents were asked, *"Once a warranty incident has occurred, what are the top criteria that can be severely influenced?"* The respondents chose answers ranged from 1 (non-impact) to 5 (catastrophic impact), as shown in Table 2. The decision makers may be interested in the responses of *Serious* and *Catastrophic*. The sum of the percentages of the respondents who chose these answers will be used to determine the order of these criteria. The *Manufacturer's reputation* followed by *Human Safety* are the top criteria influenced by warranty incidents with, 45% and 40%, respectively. The last two rows list the mean and the standard deviation of the corresponding columns, respectively.

Table 2: The most influenced criteria

Q. Once a warranty incident has occurred, what are the top criteria that can be severely influenced?					
Question	None (%)	Minor (%)	Medium (%)	Serious (%)	Catastrophic (%)
Warranty costs	5.00	20.00	45.00	25.00	5.00
Manufacturer's reputation	2.50	17.50	35.00	40.00	5.00
Human safety	2.50	17.50	40.00	30.00	10.00

Environment	2.50	30.00	45.00	20.00	2.50
Mean	3.13	21.25	41.25	28.75	5.63
Standard deviation	1.25	5.95	4.79	8.54	3.15

With regard to warranty risk mitigation tools, respondents were also asked about the existing mitigation plans used in the serious warranty risk. Their responses can be grouped into (1) mitigation plans such as recall, insurance, manufacturer support, problem diagnosis; (2) software such as customer relationship management, and (3) methods such as Delphi, historical data collection and experience.

2.1.2 Warranty-related Information

Respondents were asked about the average warranty period being offered by their organisations. Table 3 presents different warranty periods ranged from 1 year to over 5 years. The average warranty periods are 2 years and 3 years, accounted for 31.11% and 29.68%, respectively.

Table 3: Average warranty period

What is the average warranty period?	
Warranty period (Year)	Percentage (%)
1	18.99
2	31.11
3	29.68
4	3.30
5	6.60
>5	7.96
Don't know	2.36

Respondents were also asked about the average warranty cost and the average reserve fund for the future warranty claims, respectively. The responses to both questions are grouped into different categories, as shown in Table 4. The group of the average warranty cost (400,500] is the highest group chosen by respondents with 25.71%.

Table 4: Average warranty cost/ reverse fund

Please choose the appropriate average warranty cost and reserve fund.		
Amount (£)	Average warranty cost (%)	Average reserve fund (%)
<100	2.86	7.50
[100,200]	0.00	10.00
(200,300]	20.00	12.50
(300,400]	20.00	10.00
(400,500]	25.71	12.50
(500,600]	8.57	10.00
(600,700]	8.57	7.50
(700,800]	5.71	12.50
(800,900]	0.00	0.00
>900	8.57	17.50

2.1.3 Top contributors to warranty incidents and warranty costs

The contributors to warranty incidents are divided mainly into two groups: (1) internal contributors, within the warranty chain including suppliers, OEMs and dealers, and (2) external contributors, mostly the customers' errors.

Table 5 lists the top contributors to warranty incidents from the suppliers', OEMs', and dealers' viewpoints. As can be seen, 53.33% of the suppliers' respondents chose the assembly process capability at supplier(s) as the highest contributor to warranty incidents, followed by customers' errors (46.67%). There are also other contributors concerning suppliers such as faulty product design, distribution-related issues and product modification at suppliers with 40%, 40% and 40%, respectively.

Table 5: Parties' views regarding the top contributors to warranty incidents

Suppliers						
Question	Very Unlikely (%)	Unlikely (%)	Equally likely (%)	Likely (%)	Very Likely (%)	Likely+ Very likely (%)
Assembly process capability at supplier(s)	0.00	13.33	33.33	46.67	6.67	53.33
Customers error (intentional or unintentional)	0.00	0.00	53.33	6.67	40.00	46.67
Faulty product design	0.00	20.00	40.00	13.33	26.67	40.00
Distribution related issues	0.00	20.00	40.00	20.00	20.00	40.00
Product modification at suppliers	6.67	13.33	40.00	26.67	13.33	40.00
Manufacturing process capability	0.00	20.00	46.67	26.67	6.67	33.33
Assembly process capability at OEM	0.00	26.67	40.00	26.67	6.67	33.33
Diagnosis related issues	0.00	20.00	46.67	26.67	6.67	33.33
Human error or violation at suppliers	6.67	13.33	53.33	13.33	13.33	26.67
Human error at OEM (intentional or unintentional)	6.67	13.33	53.33	20.00	6.67	26.67
Miscommunication between OEM and supplier(s)	0.00	40.00	33.33	20.00	6.67	26.67
Human error at dealers (intentional or unintentional)	6.67	20.00	60.00	6.67	6.67	13.33
Mean	2.22	18.33	45.00	21.11	13.33	
Standard deviation	3.28	9.48	8.59	10.95	10.64	
OEM						
Question	Very Unlikely (%)	Unlikely (%)	Equally likely (%)	Likely (%)	Very Likely (%)	Likely+ Very likely (%)
Manufacturing process capability	0.00	20.00	20.00	40.00	20.00	60.00
Human error at OEM (intentional or unintentional)	20.00	20.00	0.00	40.00	20.00	60.00
Assembly process capability at supplier(s)	0.00	20.00	40.00	20.00	20.00	40.00
Assembly process capability at OEM	0.00	40.00	20.00	20.00	20.00	40.00
Customers error (intentional or unintentional)	0.00	20.00	40.00	20.00	20.00	40.00
Product modification at suppliers	0.00	40.00	20.00	40.00	0.00	40.00
Distribution related issues	0.00	60.00	20.00	20.00	0.00	20.00
Human error or violation at suppliers	20.00	20.00	40.00	0.00	20.00	20.00
Human error at dealers (intentional or unintentional)	20.00	40.00	20.00	0.00	20.00	20.00

Miscommunication between OEM and supplier(s)	20.00	60.00	0.00	20.00	0.00	20.00
Faulty product design	20.00	40.00	40.00	0.00	0.00	0.00
Diagnosis related issues	0.00	60.00	40.00	0.00	0.00	0.00
Mean	9.72	13.89	12.50	12.22	9.72	
Standard deviation	10.30	16.70	15.08	15.86	10.30	
Dealers						
Question	Very Unlikely (%)	Unlikely (%)	Equally likely (%)	Likely (%)	Very Likely (%)	Likely+ Very likely (%)
Manufacturing process capability	0.00	10.00	30.00	55.00	5.00	60.00
Assembly process capability at supplier(s)	5.00	15.00	25.00	50.00	5.00	55.00
Human error at OEM (intentional or unintentional)	0.00	5.00	40.00	35.00	20.00	55.00
Human error at dealers (intentional or unintentional)	0.00	5.00	40.00	30.00	25.00	55.00
Customers error (intentional or unintentional)	5.00	5.00	35.00	25.00	30.00	55.00
Faulty product design	5.00	25.00	20.00	35.00	15.00	50.00
Product modification at suppliers	0.00	15.00	35.00	35.00	15.00	50.00
Assembly process capability at OEM	5.00	20.00	30.00	40.00	5.00	45.00
Human error or violation at suppliers	0.00	5.00	50.00	25.00	20.00	45.00
Miscommunication between OEM and supplier(s)	5.00	15.00	40.00	35.00	5.00	40.00
Distribution related issues	15.00	25.00	25.00	25.00	10.00	35.00
Diagnosis related issues	5.00	10.00	55.00	25.00	5.00	30.00
Mean	3.75	12.92	35.42	34.58	13.33	
Standard deviation	4.33	7.53	10.33	9.88	8.88	

The OEMs' respondents mainly concerned about some contributors such as manufacturing process capability (60%) and human error at OEM (60%). The assembly process capability at suppliers, assembly process capability at OEM, customers' errors and product modification at suppliers are also considered as contributions to warranty incidents from the OEMs' viewpoints with 40% for each on Table 5.

With respect to the contributors to warranty incidents from the dealer respondents' viewpoints, the top contributors are the manufacturing process capability (60%), human error at suppliers (55%), human error at OEM (55%), human error at dealers (55%) and customers' errors (55%). The product modification at suppliers (50%) also concerns the dealers Table 5.

The respondents were asked, "what are the top contributors to warranty incidents?" Table 6 shows the percentages, aggregated from all of the respondents including suppliers, OEM and dealers in Table 5, towards the identification of the top contributors to warranty incidents.

The suppliers' and OEMs' respondents agreed on that the assembly process at suppliers is one of the main contributors to warranty incidents. The manufacturing process capability concerns both the OEMs and dealers. All parties agreed that the customers' errors and human error at suppliers are two of the main contributors to warranty incidents. In addition, suppliers and dealers complained about the diagnosis-related issues and human error at OEMs.

Table 6 presents the top contributors from the above parties' (suppliers, OEMs and dealers) viewpoints altogether. It can be seen that the assembly process capability at supplier(s), manufacturing process capability, customers' errors, and human error at OEM account for the highest percentages of the respondents with 52.50%, 50%, 50% and 45%, respectively.

Table 6: The top contributors to warranty incidents

What are the top contributors to warranty incidents?						
Question	Very Unlikely (%)	Unlikely (%)	Equally likely (%)	Likely (%)	Very Likely (%)	Likely+ Very likely (%)
Assembly process capability at supplier(s)	2.50	15.00	30.00	45.00	7.50	52.50
Manufacturing process capability	0.00	15.00	35.00	42.50	7.50	50.00
Customers error (intentional or unintentional)	2.50	5.00	42.50	17.50	32.50	50.00
Product modification at suppliers	2.50	17.50	35.00	32.50	12.50	45.00
Human error at OEM (intentional or unintentional)	5.00	10.00	40.00	30.00	15.00	45.00
Faulty product design	5.00	25.00	30.00	22.50	17.50	40.00
Assembly process capability at OEM	2.50	25.00	32.50	32.50	7.50	40.00
Distribution related issues	7.50	27.50	30.00	22.50	12.50	35.00
Human error or violation at suppliers	5.00	10.00	50.00	17.50	17.50	35.00
Human error at dealers (intentional or unintentional)	5.00	15.00	45.00	17.50	17.50	35.00
Miscommunication between OEM and supplier(s)	5.00	30.00	32.50	27.50	5.00	32.50
Diagnosis related issues	2.50	20.00	50.00	22.50	5.00	27.50
Mean	3.75	17.92	37.71	27.50	13.13	
Standard deviation	1.99	7.75	7.57	9.35	7.77	

Obviously, the main contributor to warranty costs is the aforementioned warranty incidents. But the magnitude of the costs of those incidents varies. Additionally, there may be other hidden costs leading to an increase in warranty costs. The respondents were therefore asked: *"In addition to the aforementioned warranty incidents, what the other contributors to warranty costs?* Table 7 shows that 60% of respondents chose the provision of warranty services (labour costs, etc.) and it is the top contributor to warranty cost among others listed in the table. Material movement and its storage expenses were chosen by the respondents (47.50%) to be the second contributors to warranty cost.

Remarkably, customers' fraud (37.50%) has more impact on the warranty cost than dealers' fraud (27.50%), which differs from the statement that the highest fraudulent claims are from warranty service agents' fraud (Kurvinen et al., 2016).

Table 7: Contributors to warranty cost

In addition to the aforementioned warranty incidents, what the other contributors to warranty costs?						
Questions	Very Unlikely (%)	Unlikely (%)	Equally likely (%)	Likely (%)	Very Likely (%)	Likely+ Very likely (%)
Provision of warranty services (labour costs, etc.)	2.50	12.50	25.00	42.50	17.50	60.00
Material movement and its storage expenses	0.00	22.50	30.00	32.50	15.00	47.50
Customers fraud	5.00	20.00	37.50	27.50	10.00	37.50
Warranty administration	0.00	22.50	40.00	27.50	10.00	37.50
Different exchange rates (spare parts)	7.50	25.00	37.50	17.50	12.50	30.00
Dealer fraud	15.00	32.50	25.00	20.00	7.50	27.50
Mean	5.00	22.50	32.50	27.92	12.08	
Standard deviation	5.70	6.52	6.71	9.00	3.68	

As stated before, the provision of warranty services involves different kind of risks, one of which is customers' dissatisfaction. Hence, the questionnaire includes a question: "*In relation to warranty services provision, what are the top contributors to customers' dissatisfaction*?" The respondents chose service time followed by service quality to be the top contributors to customers' dissatisfaction with 65% and 60%, respectively (Table 8).

Table 8: Contributors to customers' dissatisfaction

In relation to warranty services provision, what are the top contributors to customers' dissatisfaction?						
Question	Very Unlikely (%)	Unlikely (%)	Equally likely (%)	Likely (%)	Very Likely (%)	Likely+ Very likely (%)
Service time	2.50	15.00	17.50	47.50	17.50	65.00
Service quality	5.00	5.00	30.00	40.00	20.00	60.00
Customer care	7.50	12.50	40.00	27.50	12.50	40.00
Mean	5.00	10.83	29.17	38.33	16.67	
Standard deviation	2.50	5.20	11.27	10.10	3.82	

2.1.4 Warranty Hazards from Warranty Chain Perspective

In order to gain a better understanding of the role of the warranty chain, respondents were asked *"Which of the following activities (or part of) are outsourced?"* and they should tick all answers that apply. Table 9 shows that the distribution services accounts for the highest percentage (29.31%) of the outsourced activities. Warranty services are the second highest outsourced activity (25.58%). The respondents (15.12%) showed little interest in sourcing the product design than the aforementioned activities.

Table 9: Outsourced activities

Which of the following activities (or part of) are outsourced?	
Activity	Percentage (%)
Distribution	29.31
Warranty services	25.58
Product manufacturing	24.68
Product designing	15.12
Don't know	5.31

Another difficulty can be brought due to such outsourcing activities is the collaboration between those parties, particularly, the exchange of warranty-related data. Undoubtedly, the presence of the required information at the proper time allows decision makers or engineers to take the right action at the proper time. Therefore, the respondents were asked *"To what extent would/will you be able to access warranty-related data (in real-time or almost)?"* and each respondent can choose the appropriate answer among different 5 choices started from *"Not at all"* to *"To a very great extent"*.

Their responses are presented in Table 10 based on their organisation's types. To some extent dealers and OEMs can access suppliers' warranty-related data, with an average of 3.6 and 3.47 out of 5, respectively. Generally, the collaboration between those parties is limited or insufficient to improve the process of warranty hazard identification.

Table 10: To what extent an organisation can access to another organisation's warranty data

	Supplier	OEM	Dealer
Supplier		3.00	3.00
OEM	3.60		3.40
Dealer	3.47	3.21	

In order to find which the main contributor to products' failures among those parties and customers is, the respondents were asked *"Rate the following parties according to their contributions to the products' failures".* The respondents answered this question by rating the potential contribution of each party to warranty incidents based on stars rating 1*-5*. Table 11 shows the contribution of each party in the products' failures. If we combine the percentages of respondents who chose 4 and 5, the customers followed by OEMs and suppliers are the top contributors to products' failures with 67.50%, 64.10% and 58.97%, respectively.

Table 11: Parties contributions in the products' failures

Rate the following parties according to their contributions to the products' failures.						
Question	1* (%)	2* (%)	3* (%)	4* (%)	5* (%)	4*+5* (%)
Customers	5.00	10.00	17.50	47.50	20.00	67.50
OEMs	2.56	10.26	23.08	51.28	12.82	64.10
Suppliers	7.69	7.69	25.64	51.28	7.69	58.97
Dealers	12.82	15.38	33.33	17.95	20.51	38.46
Other	25.64	12.82	30.77	20.51	10.26	30.77
Mean	10.74	11.23	26.06	37.71	14.26	
Standard deviation	9.16	2.95	6.27	16.96	5.77	

With regards to human error, respondents were asked, *"What are the top contributors to human errors causing warranty incidents?"* as shown in Table 12. It is evident that the experience needed and skills and the lack of training are the highest contributors to human error, with the percentage of the respondents 55% and 55%, respectively.

Table 12: Contributors to human error

What are the top contributors to human errors causing warranty incidents?						
Question	Very Unlikely (%)	Unlikely (%)	Equally likely (%)	Likely (%)	Very Likely (%)	Likely+ Very likely (%)
Experience needed and skills	5.00	12.50	27.50	37.50	17.50	55.00
Lack of training	2.50	22.50	20.00	27.50	27.50	55.00
Workplace (sapce, environment, etc.)	7.50	25.00	32.50	27.50	7.50	35.00
Product design (required equipment, complexity, etc.)	5.00	25.00	35.00	25.00	10.00	35.00
Observation capability	5.00	10.00	52.50	17.50	15.00	32.50
Mean	5.00	19.00	33.50	27.00	15.50	

Standard deviation	1.77	7.20	12.07	7.16	7.79	

2.2 Findings and Discussion

Although warranty risk management is an important field of a study, little work has been done on it. The objectives of this research, as mentioned above, is mainly to design a generic WaRM framework and warranty hazard taxonomy that may help further studies in such a field. To this end, we started analysing the literature to find the existing tools used to identify and assess warranty hazards and to identify the top contributors to warranty incidents and costs from a product lifecycle perspective. The above questionnaire survey was then carried out to obtain an in-depth understanding of the existing WaRM practice. Based on the findings of the questionnaire survey, we will design a generic WaRM framework in Section 3.

Based on the questionnaire data and the analysis of the existing literature, the main findings will be discussed to construct the WaRM framework and warranty hazard taxonomy.

Firstly, the main findings relating the existing tools and practice of WaRM include:

- The most common tool used to identify warranty hazards is the root cause analysis technique. This technique is designed for understanding the root cause of a problem. Although it has some advantages, the main problem is that it needs a lot of time to identify the root cause of the problem. The time issue is the concerns of most respondents as they stated that the limitation of the existing tools is the time needed to respond to the emerged issues. As such, the root cause analysis technique might not be an appropriate tool in identifying warranty hazards (incidents) when the time is crucial. For example, a manufacturer may recall the failed products at the early stage of products' failures before getting in a more complex situation such as being fined or paid for potential casualties or deaths. Therefore, using the advanced technologies to identify warranty hazards is needed, in particular with the complex products (e.g. vehicles) where the level of uncertainty can be high. From this point, carmakers may need to shift from the conventional warranty hazard identification tools to more advanced ones.
- The most common tool used to assess warranty risks is the failure mode effect and criticality analysis (FMECA). Although this tool is widely used in analysing reliability-related failures, its accuracy may not be reliable when analysing complex products.
- Manufacturers' reputation and warranty costs are the most susceptible criteria to warranty risks.

Overall, the existing tools and practice of WaRM used by carmakers need to be updated and developed to deal with warranty risks. The main issue needs to be addressed is the time needed to identify warranty hazard, which might be addressed by employing advanced technologies such as Big Data analytics.

Secondly, the main findings relating the top contributors to warranty incidents and costs include:

- The assembly process capability at suppliers, customers' errors and human error, at different parties (suppliers and OEMs), are the prominent contributors to warranty incidents. The lack of training and experience are the main drivers to human error, whereas customers' errors can occur unintentionally due to poor information on how to use the product, lack of training or misuse of the product. In addition, the manufacturing process capability is one of the main sources of warranty incidents from both viewpoints of the OEMs and dealers.
- The collaboration among parties is limited, particularly, the accessibility to warranty-related data between parties (suppliers, OEM and dealers) is restricted. The lack of collaboration may incur a considerable warranty cost. For example, the non-failure found (NFF) problem, which accounts for a large portion of warranty claims, can be reduced by sharing warranty-related data in the required time.

- Customers' fraud contributes more to warranty costs than warranty services providers' fraud. As such, manufacturers may need to find solutions to deal with the frauds such as imposing more restrictive rules to control the NFBR (non-failed but reported) problem.
- Outsourcing design activities showed little interest than other activities, which may be because the manufacturers want to ensure that the product design is thoroughly tested. Therefore, the in-house design allows them to test and improve the product design until the target reliability level is achieved and then outsourcing the rest activities such as manufacturing some systems or sub-systems. The outsourcing of various activities can provide organisations with more flexibility and more focus on improving the existing products and developing new ones. However, improperly managing of such activities can increase warranty costs.
- The top contributor to human error, in relation to warranty incidents, is a lack of training and experience, which implies that technicians have not received adequate training primarily, on the new and complex innovations. This also illustrates the significance of planning carefully for the future warranty services at the design stage. Employing experienced labour can mitigate diagnostic errors and hence the problem of NFF can be reduced.

It can be concluded that there are different contributors to warranty incidents and costs from different perspectives (product lifecycle and warranty chain). However, the most prominent contributors from the product lifecycle perspective are assembly process capability, customers' errors and human error at different parties, whereas the collaboration or miscommunication problem is the top contributor from the warranty chain perspective.

Based on the above findings and discussion, we will develop a WaRM framework in the following section.

3 A WaRM framework

This section will focus on designing a generic WaRM framework based on the above findings.

Similar to the definition of risk management defined by ISO 31000(Purdy, 2010), WaRM is the process that identifies potential warranty hazards associated with the warranty programme across the product's lifecycle, assesses the associated risks occurring during warranty period, mitigates, monitors and reviews those risks (See Figure 1). As such, the main role of WaRM is to maximise acceptable events and reduce the impact of unacceptable ones or avoid them during the warranty period.

3.1 Potential Criteria for Assessing Warranty Risks

Once the warranty hazards have been identified, a decision criterion is an important consideration. However, the following criteria are most likely to be influenced by the warranty hazards:

- Warranty cost: Warranty costs can be direct expenses as a result of warranty incidents such as product design-related problems, or indirect expenses as a result of various activities required to improve warranty services such as logistics, different exchange rate, and warranty administration.
- Customers' dissatisfaction: It may occur as a result of different reasons such as increasing product failure rate, long service time, mistreatment of the customers or low level of service quality.
- Manufacturers' reputation: As a result of huge recall (reliability or safety related issues) and the length of media coverage, the manufacturer reputation may be negatively influenced.

There are also other criteria that can be adopted to measure such risks, including human safety and environmental impacts.

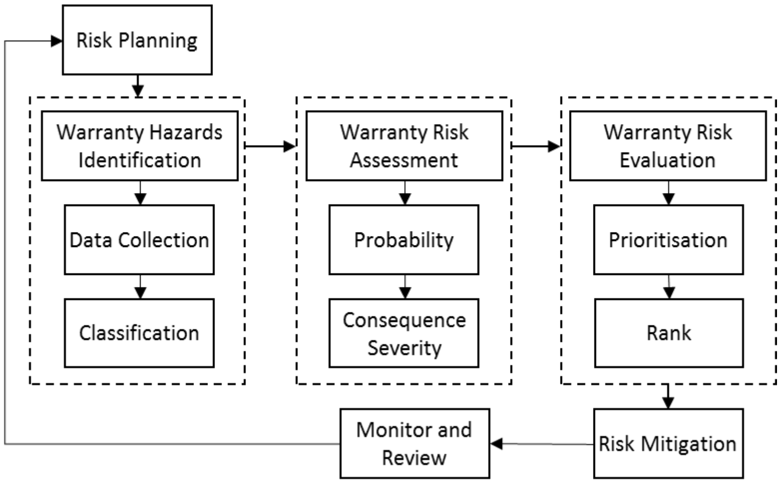

Figure 1: WaRM process

3.2 A WaRM Framework

The ISO 31000 risk management framework (Purdy, 2010) can be adopted in the development of the WaRM framework. As a result, a WaRM framework, as shown in Figure 2, is developed and interpreted as the follows.

1) Determining the internal and external stakeholders who should be communicated or consulted to gain inputs for each step of the framework. The engineering, marketing, finance, legal and accounting departments are examples of internal stakeholders, whereas suppliers, dealers, and distributors are examples of external stakeholders affecting the decision of managing warranty risk. The communication and consultation is a continuous process through the all WaRM steps and important to understand the objectives of the stakeholders. Accordingly, such objectives can be considered in setting the warranty risk plan.
2) Setting the warranty risk plan by determining warranty programme objectives and the factors that influence the achievement of such objectives which should be in line with the overall business strategy. Setting the mitigation plans by consulting experts or learning from the similar cases occurred at competitors is necessary.
3) Identifying warranty hazards: More attention should be paid to this step as the above case study showed the stated limitations of the existing WaRM tools which are mainly about the time needed to detect the warranty hazard. This step is therefore the cornerstone of this framework as the warranty programme involves a high level of uncertainty, due to the complexity of products and the long warranty period, which makes it difficult to be planned at the previous steps. Additionally, since warranty management touches many parts of the manufacturer, the identification of warranty-related hazards needs for collecting data and information from different sources. As such, this step is divided into four phases as follows.
   - *Data collection:* Data should be collected from all stakeholders, including the internal and external stakeholders. Due to difficulties in obtaining real-time data from such stakeholders, other sources of data such as customers comments on social media can be a good source. Combining both sources of data can improve the efficiency of the warranty hazard identification process.
   - *Data cleansing:* The collected data may include noisy data or/and incompatible with the manufacturer database system, so one needs to cleanse and prepare such data to obtain understandable information.
   - *Data analysis:* The acquired information needs to be analysed to identify warranty hazards and its characteristic.
   - *Classification:* The classification of the identified hazards is then used to facilitate the rest steps of WaRM. For example, it can be broadly classified warranty hazard design-related, manufacturing-related, warranty-servicing-related, customer-related or information-related hazard.

4) Assessing warranty risks: The likelihood of the risk associated with an identified hazard can be estimated by analysing warranty claim data or use experts judgements in the case of the new products without an operational history.
5) Evaluating such risks including prioritising and ranking them based on their severity on warranty cost and the organisation reputation. Then the WDM can evaluate such risk and decide the acceptable and unacceptable ones.
6) Mitigating such risk based on the outcomes of the above steps 3) & 4) and based on the mitigation plans set in step 2).
7) Visualising such risks to gain a better understanding of the monitoring process and the warranty risk plan. The monitoring and review step is a continuous process with the all WaRM steps. For example, warranty risk plan including procedures liabilities documentation and others need to be updated responding to the new changes. Likewise, the approaches used to identify, assess, evaluate and mitigate warranty risk will be updated, if necessary, according to such changes.

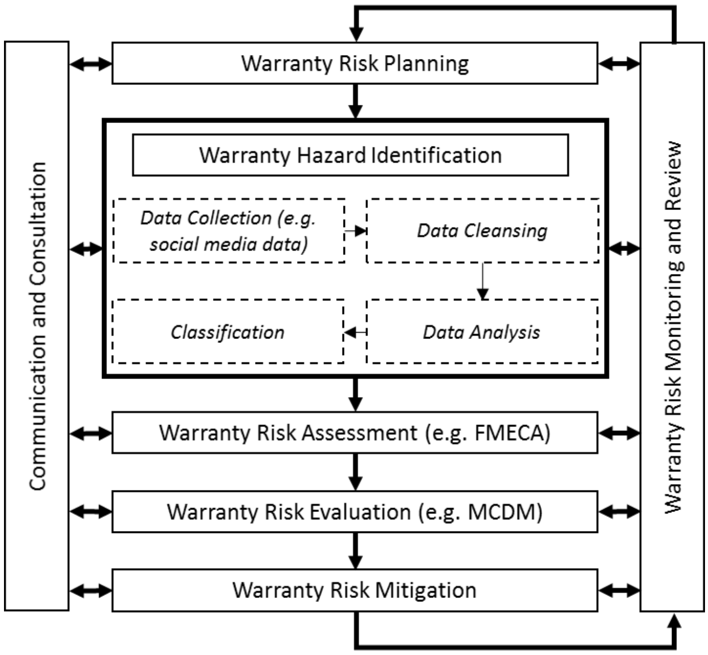

Figure 2: A WaRM framework

4 Warranty Hazard Taxonomy from a Warranty Chain Perspective

Since warranty hazard identification is an important step in WaRM, it is essential to be processed from the strategic point of view to ensure two main objectives: reducing the warranty cost and retaining customers' satisfaction. This section therefore focuses on the top contributors to warranty incidents and costs, suggested from the above case study and the design of the warranty hazard taxonomy, as shown in Figure 3. Such a taxonomy is adopted from Tang & Musa (2011) and categorised into: material flow risk, financial flow risk and information flow risk.

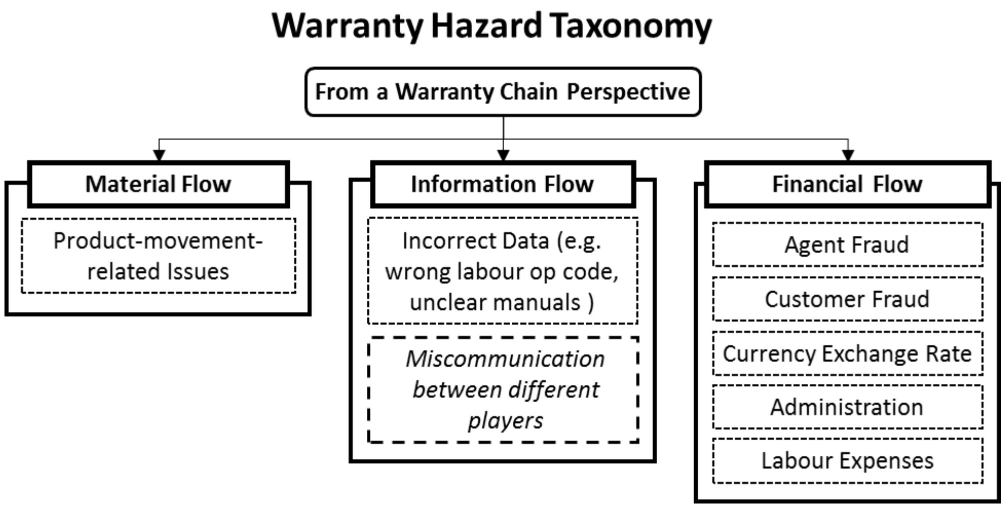

Figure 3: Warranty hazard taxonomy from warranty chain perspective

4.1 Material flow

The material flow is involved with the warranty incidents relating to the material and its movement (e.g. spare parts, subsystems, etc.) from one party to another. The movement of materials, from the suppliers to the OEM and then to the customers (or in the reverse logistics), involves different kinds of hazards, including packing, shipping, handling processes and excessive storage. In addition, the other contributors to warranty incidents, including human error at each stage of the product lifecycle, are identified in the above case study. At the design stage, human error may occur as a result of the shareholders or market pressures, which may result in faulty product design and low-reliability products. Likewise, at the manufacturing stage, problems such as assembly process capabilities at both suppliers and OEMs are serious issues that may increase warranty claims. At the operating stage, customers' errors form the largest portion of the warranty incidents. With regard to the warranty servicing stage, it contributes to warranty incidents as a result of the failure diagnosis-related issues, among others.

4.2 Information flow

One of the identified contributors to warranty incidents, suggested from the above case study, is the lack of collaboration between parties. All parties have limited access to warranty related data, which may delay the response to the emerged hazard or the required developments.

In the warranty chain, there are different sources of important data including warranty data, service quality, customers demand, inventory status, customers' feedback and competitors' news. Analysing such data and share it with parties can provide highly valuable information protecting manufacturers from undesired events.

Warranty data (claims data and supplementary data) has useful information regarding product quality and reliability (Wu, 2012). Failing to obtain such information at the proper time might lead to inappropriate decisions, which may increase warranty cost or may also affect the whole business. Although warranty data is the most important source of products' field test, it takes time (up to 2 months) to be collected and analysed (BearingPoint, 2007). The warranty-related data issues termed as coarse data which were grouped by Wu (2012) into the following issues, for example:

- Aggregated data: Claims may be grouped based on the age (e.g. 0-30 days) and then sent to the analysts.
- Data lag: Such delay might result from sales or reporting process that needs time to be verified before submitting.
- Incomplete censored data: It is caused by the expiration of the warranty period.

The validation process of warranty claims can bring another problem. It includes two undesired issues: the first one is to process such validation in a quick way in order to handle a large number of warranty claims easily. However, there is a possibility of not detecting the WSP's or customer's fraud. The second issue, if warranty claims are thoroughly validated in order to protect manufacturers from the agents' fraud, it might delay the response to warranty claims which, in turns, raises the dispute between the manufacturers and the WSPs.

Other information-related issues are as follows.

- *Incorrect data:* It refers to the incorrect qualitative data such as the failure symptoms given by the customer and the technician comments. Also, it refers to the wrong diagnosis which may occur from opting the wrong failure code by technicians.
- *Information management:* The information obtained from warranty data is highly valuable. Hence, such information must be well managed in relation to risks resulting from information interruption, information security, information privacy, compatibility and integration of systems between WSPs and other parties (OEMs and suppliers), information delays and lack of information transparency between the aforementioned parties.
- *Miscommunication between parties*: Managing warranty-related data in an efficient way can provide useful information. If such data is available, the question is that to what extent such data can be adequately shared between parties. Increasing collaboration between parties should result in a reduction in warranty incidents and costs and meanwhile retain customers' satisfaction. For example, product design-related data and manufacturing-related data may be shared between suppliers and OEM in order to improve the reliability of the product and reduce the inferior raw material and unauthorised changed made by suppliers. Additionally, the collaboration between WSPs and the OEM will allow the later to monitor the WSPs activities. The better communication may allow WSPs to access the product details to ensure a high level of service quality, particularly, in the maintenance of complex products.

Customers are the main players in the information chain as their collaborations with the rest parties can provide some benefits. They might receive online technical support from the OEM as well as they can send useful information about product usage-related data to help manufacturers to determine their demands and carry out the required improvements.

4.3 Financial Flow

The financial flow in this context means the top contributors to warranty costs that were determined in the questionnaire study. Apparently, the main contributor is the aforementioned warranty incidents. There are, however, other contributors such as:

- *WSP fraud:* Warranty service providers may deceive the OEM in different ways, and some of them consider the fraud is the main source of revenue (Kurvinen et al., 2016). For example, they might replace or repair products without entitlement in order to increase claims numbers.
- *Customer fraud:* It is found that the customers' fraud is higher than WSP fraud (dealer fraud). One of the prominent examples of the customers' fraud is non-failed but reported (NFBR) issue (Wu, 2011), for example.
- *Currency exchange rate:* The provision of warranty service can last for five years or more. During this period, the prices of spare parts may show an increase[3] (WarrantyWeek, 2015).
- *Administration:* The expenses spent on managerial work, legal, accounting among others (Murthy and Djamaludin, 2002).
- *Labour expenses:* Such expenses including salaries, compensations, training among others. In the above case study, the provision of warranty services including labour expenses is the top

[3] Retrieved from: http://www.warrantyweek.com/archive/ww20151022.html (October 22, 2015)

contributor to warranty costs. It is found that even the warranty incidents have decreased, warranty costs have not changed due to the labour expenses (BearingPoint, 2007).

5 Conclusions

Although offering a longer warranty period may increase product sales volume, it brings various risks that can have a significant impact on the manufacturers' profits and customers' satisfaction. As such, this paper has achieved the following:

- Analysed the existing publications regarding warranty risk management (WaRM).
- Carried out a questionnaire survey to gain a better understanding of the following issues:
  - The existing tools used by organisations to manage warranty risks and hence determining their limitations.
  - The top contributors to warranty incidents and costs.
- Designed a generic warranty hazard taxonomy with the use of social media data as an early warning tool to identify warranty hazards.
- Systematically analysed the top contributors to warranty incidents and costs from a warranty chain perspective, and the role of human error are discussed at each stage.
- Designed a warranty hazard taxonomy.

It is found that the assembly process capability at suppliers and human error at OEMs and suppliers plays an important role in each stage of the product lifecycle. In addition, customers' errors and miscommunication between different parties contribute to warranty incidents.

In practice, the WaRM framework will help WDM to reform their thinking towards the importance of adapting the new technologies to overcome the problem of identifying warranty hazards at the early stage.

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