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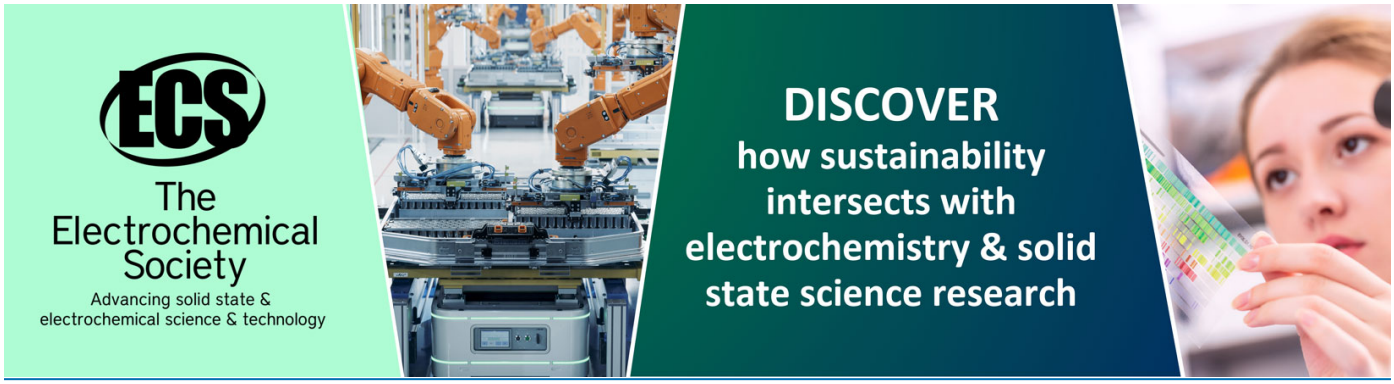

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Development of Risk Optimisation Model for Oil and Gas Transportation Pipeline Routes

L Kraidi [1, 2,*], R Shah [1], W Matipa [1], F Borthwick [1], Khalid Hashim [3]

[1] Department of the Built Environment, Faculty of Engineering and Technology, Liverpool John Moores University, UK.
[2] PhD Student, Henry Cotton Building, Faculty of Engineering and Technology, Liverpool John Moores University, UK.
[3] Department of Civil Engineering, Faculty of Engineering and Technology, Liverpool John Moores University, UK.

* Corresponding Author: L.A.Kraidi@2016.ljmu.ac.uk

Abstract. Identifying safe routes for the pipelines that transport Oil and Gas (O&G) products is a challenging topic in the current environment; particularly in the insure countries. Because the relevant data about the probability and severity levels of the Risk Factors (RFs) that affect the safety of these pipelines are rare. Which makes the existing risk assessment tools ineffective to analyse these RFs and identify safe route for these pipelines. Hence, this paper aims to develop a risk assessment tool that can identify safe routes for the new O&G pipelines in Iraq in a systematic way using the following steps. Firstly, an industry-wide questionnaire survey was conducted to gather the data about the probability and severity levels of the RFs in such projects in Iraq. Secondly, the Fuzzy Inference System (FIS) in MATLAB was used to analyse and rank the RFs. Because the FIS can reduce the uncertainty in risk analysis, which results from the lack of data and the biasness of stakeholder's judgments about the RFs. Thirdly, the existing information from the new pipelines projects were analysed to identify the potential RFs in the proposed routes for these projects. As the O&G pipeline network in Iraq is above-the-ground, this paper focused on the RFs that affect this type of pipelines. Fourthly, the safest route for the new pipeline was identified by optimising the risk index value for each route. While, the route that has less value of risk index is the safest route. This paper analysed the five routes that were suggested to build a new gas export pipeline in Waist in Iraq. The pipeline will transport the extracted gas from Badra filed to the shipping points in Iraq. It was found that route number 4 is the safest route for this pipeline.

1. Introduction

Oil and Gas Pipelines (OGPs) must be planned, designed, installed, operated and maintained regarding the safety requirements to transport the petroleum products safely. However, several Risks Factors (RFs) are threatening the safety of these projects, such as terrorism, sabotage, thefts, corrosion, design and construction defects, natural hazards, operational errors and many more. Meanwhile, the current risk assessment tools are inaccurate to analyse the RFs in OGP projects in the developing countries due to the data scarcity and lack of research about them in these countries. As stated by Kraidi et al., [1], the risk management system in OGP projects in Iraq suffers from the scarcity of data about the probability and severity levels of the RFs in these projects. The alternative way of identifying and analysing the RFs in such a situation is via conducting a literature review about the RFs in OGP projects and collecting the stakeholders' perceptions about them [2]. Nevertheless, analysing the RFs based on the stakeholders' perceptions results in uncertain results. Because the stakeholders have different

perceptions about the probability and severity levels of the RFs [3]. Therefore, the RFs in this paper will be analysed using the Fuzzy Inference System (FIS) in MATLAB. Because the FIS uses linguistics terms (e.g. very low, low, moderate, high and very high) to analyse the RFs, which is useful to calculate the Risk Index (RI) of the factors when there are neither sharp boundaries nor precise values of their probability and severity levels [4].

2. Aims and objectives

The purpose of the paper, therefore, is to develop a risk assessment tool that helps in analysing the RFs in the pipelines' projects and choosing safe routes for the new projects in a systematic way. This tool will analyse the OGP projects in two cities southern of Iraq, which are Waist (Al Kut) and Basra. Because the current risk management system in these projects is inadequate, which obstructs gas export activities. Figure 1 shows the flowchart of the risk assessment tool.

3. Research approach

Figure 1 explains the flowchart of the risk assessment tool.

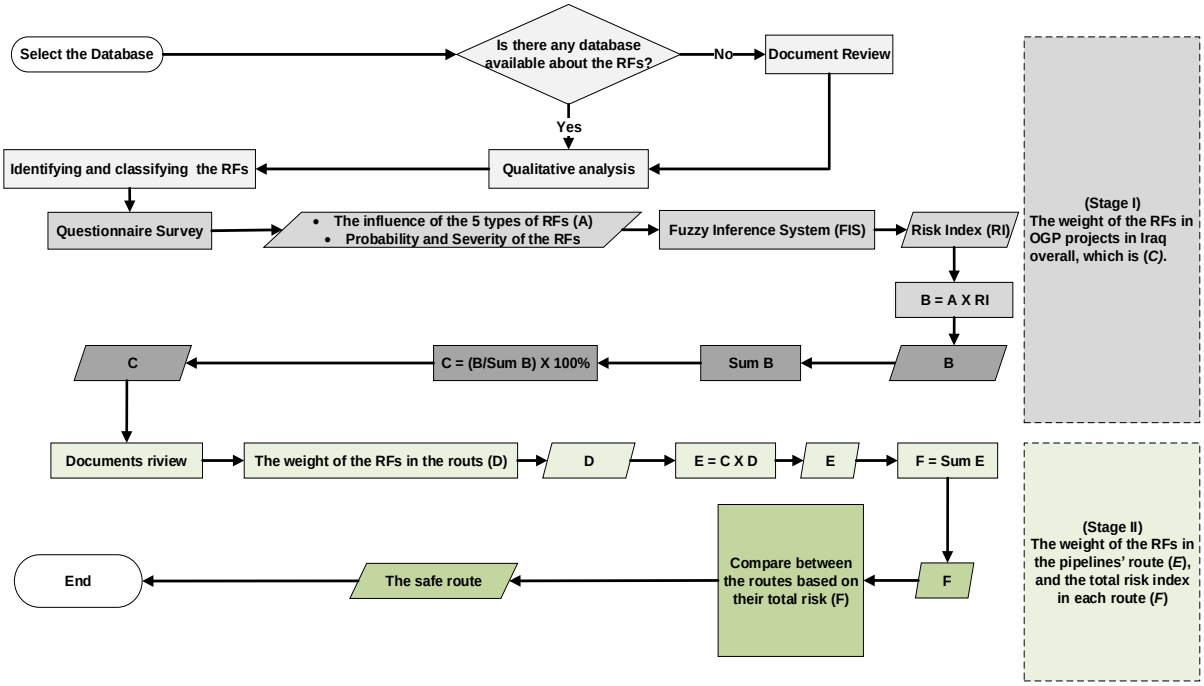

Figure 1. The flowchart of the risk assessment tool.

Following figure 1, the risk assessment tool works in two stages. In stage I, extensive investigations were carried out to identify the RFs in OGP projects in different countries and circumstances to overcome the problem of data scarcity about them in Iraq. The identified RFs were classified into five groups based on their type. Then, the RFs were evaluated via a questionnaire survey that was distributed amongst the stakeholders in OGP projects in Iraq using an online survey tool. The outputs of the survey were the weight of each group of the RFs (A). As well as the probability and severity levels of the RFs, which were used as inputs for the FIS in MATLAB to calculate the RI of the RFs, see Figure 2. Appendix A shows examples of the questionnaire survey. Appendix A shows the size of the sample and the response rat. B is the weight of the RF that considers the weight of its groups (A) and its value of RI. The results of (Stage I) of risk analysis are shown in **Error! Reference source not found.**.

$$B = A \times RI \tag{1}$$

C is the weight of the RFs from 100%,

$$\mathrm{C} = (\mathrm{B} \,/\, (\mathrm{Sum\ B})) \times 100\% \tag{2}$$

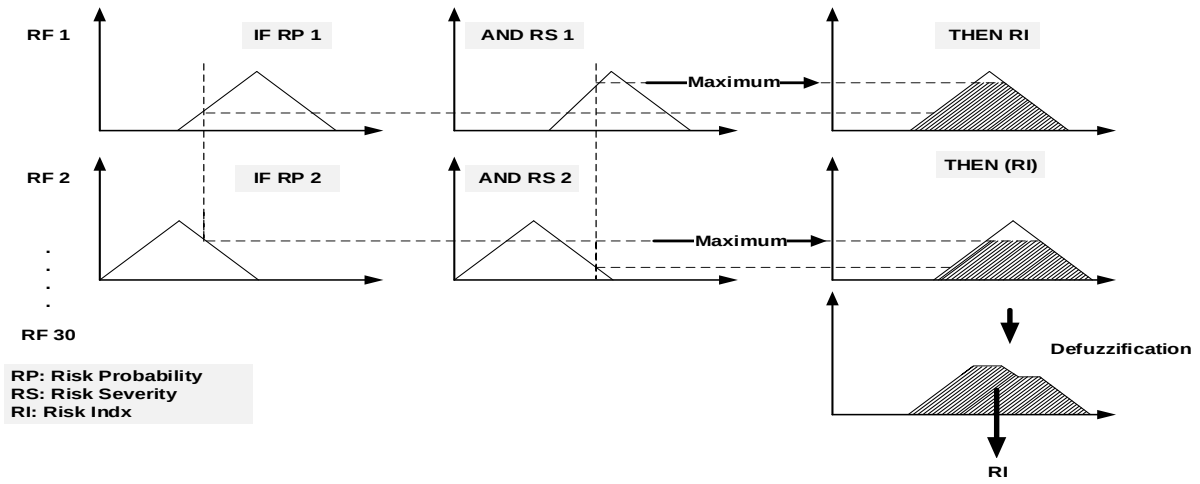

Figure 2. The diagram of the Fuzzy Inference System (FIS).

Stage II of the risk assessment tool is about analysing the RFs in specific routes of OGPs. This paper has analysed the five proposed routes for a new gas pipeline, which will be built from Badra gas field in Waist to Basra in order to export the extracted gas from that field via the sea. The available documents about these five routes were subjectively analysed to identify the RFs that might threaten the pipelines in these routes. D is the weight of the RFs in the route. Based on the document analysis, in the case that the RF is threatening the pipeline, then $\boldsymbol{D = 1}$; otherwise, $\boldsymbol{= 2}$. E is the final weight of the RFs in the route.

$$E = C \times D \tag{3}$$

Where ***C*** is the weight of the RFs in OGP projects in Iraq overall and ***D*** is the weight of the RFs within the specific route. ***F*** is the total risk index in the route.

$$F = SUM(C) \tag{4}$$

The route that has less value of ***F*** is the safest route. Because it has the less total impact of the RFs. The results of analysing the OGPs' routes are shown in **Table 2**.

Table 1. The identified RFs from the literature review and their values of probability, severity and index.

RFs [1-3 and 5,6]	Type*	A	Probability	Severity	RI	B	C
Terrorism, sabotage and the security risk	S&S	2.84	3.995	4.490	3.99	11.33	5.43
Stealing the products	S&S		3.692	4.081	3.75	10.65	5.10
Public awareness	S&S		3.712	4.106	3.80	10.79	5.17
Staff threats	S&S		3.323	3.571	3.35	9.51	4.55
Socio-political effects	S&S		3.449	3.611	3.49	9.91	4.75
Leakage of sensitive information	S&S		2.980	3.399	3.38	9.60	4.60
Corruption	R&L	1.45	3.980	4.323	3.87	5.61	2.69
The absence of the law on TPD	R&L		3.606	3.682	3.54	5.13	2.46
Lack of risk management practice	R&L		3.530	3.652	3.51	5.09	2.44
Lack of proper training	R&L		3.646	3.859	3.71	5.38	2.58
Lack of risk registration	R&L		3.566	3.662	3.60	5.22	2.50
Little research on this topic	R&L		3.621	3.697	3.55	5.15	2.46
The geographical location	PL	2.37	3.717	4.192	3.76	8.91	4.27
The pipeline is easy to access	PL		3.631	3.773	3.57	8.46	4.05
Land ownership conflicts	PL		3.495	3.646	3.68	8.72	4.18
Geological risks	PL		2.747	3.182	3.17	7.51	3.60
Vehicles accidents	PL		2.465	2.970	2.80	6.64	3.18
Animals accidents	PL		1.894	2.020	1.95	4.62	2.21
Improper safety regulations	HSE	1.89	3.687	3.960	3.70	6.99	3.35
Improper inspection and maintenance	HSE		3.657	3.899	3.69	6.97	3.34
The risk related to the aboveground pipeline	HSE		3.667	3.949	3.70	6.99	3.35
Limited warning signs	HSE		3.626	3.732	3.56	6.73	3.22
Inadequate risk management	HSE		3.227	3.505	3.48	6.58	3.15
Natural disasters	HSE		2.652	3.066	3.10	5.86	2.81
Corrosion	OC	1.45	3.687	3.990	3.72	5.39	2.58
The weak ability to manage the risk	OC		3.631	3.848	3.67	5.32	2.55
Shortage of modern equipment	OC		3.667	3.924	3.68	5.34	2.55
Design, construction and material defects	OC		3.333	3.611	3.64	5.28	2.53
Operational errors	OC		3.101	3.409	3.30	4.79	2.29
Hacker attacks on the system	OC		3.066	3.066	3.03	4.39	2.10

*Security and Safety (S&S), Rules and Regulations (R&R), Pipeline Location (PL), Health Safety and Environment (HSE) and Operations Consent (OC)

Table 2. The results of analysing the RFs and testing the pipelines routs.

RFs	C	Route 1		Route 2		Route 3		Route 4		Route 5	
		D1	E1	D2	E2	D3	E3	D4	E4	D5	E5
Terrorism, sabotage and the security risk	5.43	0	0.00	1	5.43	1	5.43	0	0.00	0	0.00
Stealing the products	5.10	1	5.10	1	3.20	1	5.10	0	0.00	0	0.00
Public awareness	5.17	1	5.17	1	3.24	1	5.17	1	5.17	1	5.17
Staff threats	4.55	0	0.00	1	2.86	0	0.00	1	4.55	0	0.00
Socio-political effects	4.75	0	0.00	1	2.98	1	4.75	1	4.75	0	0.00
Leakage of sensitive information	4.60	1	4.60	0	0.00	1	4.60	0	0.00	1	4.60
Corruption	2.69	1	2.69	1	3.30	1	2.69	1	2.69	1	2.69
The absence of the law on TPD	2.46	1	2.46	1	3.02	1	2.46	1	2.46	0	0.00
Lack of risk management practice	2.44	1	2.44	1	2.99	1	2.44	1	2.44	1	2.44
Lack of proper training	2.58	1	2.58	1	3.16	1	2.58	1	2.58	1	2.58
Lack of risk registration	2.50	1	2.50	1	3.07	1	2.50	1	2.50	1	2.50
Little research on this topic	2.46	1	2.46	1	3.03	1	2.46	1	2.46	1	2.46
The geographical location	4.27	0	0.00	1	3.21	1	4.27	0	0.00	0	0.00
The pipeline is easy to access	4.05	1	4.05	1	3.05	1	4.05	0	0.00	1	4.05
Land ownership conflicts	4.18	1	4.18	1	3.14	0	0.00	1	4.18	1	4.18
Geological risks	3.60	0	0.00	1	2.70	1	3.60	0	0.00	1	3.60
Vehicles accidents	3.18	0	0.00	1	2.39	1	3.18	0	0.00	1	3.18
Animals accidents	2.21	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Improper safety regulations	3.35	1	3.35	1	3.16	1	3.35	1	3.35	1	3.35
Improper inspection and maintenance	3.34	1	3.34	1	3.15	0	0.00	0	0.00	1	3.34
The risk related to the aboveground pipeline	3.35	1	3.35	1	3.16	0	0.00	1	3.35	1	3.35
Limited warning signs	3.22	0	0.00	1	3.04	1	3.22	0	0.00	1	3.22
Inadequate risk management	3.15	1	3.15	1	2.97	1	3.15	1	3.15	1	3.15
Natural disasters	2.81	1	2.81	0	0.00	1	2.81	0	0.00	1	2.81
Corrosion	2.58	0	0.00	1	3.17	1	2.58	1	2.58	0	0.00
The weak ability to manage the risk	2.55	1	2.55	1	3.13	1	2.55	1	2.55	1	2.55
Shortage of modern equipment	2.55	1	2.55	1	3.14	1	2.55	1	2.55	1	2.55
Design, construction and material defects	2.53	1	2.53	0	0.00	1	2.53	0	0.00	1	2.53
Operational errors	2.29	1	2.29	1	2.81	1	2.29	0	0.00	1	2.29
Hacker attacks on the system	2.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Sum =	100.00	F1=	64.12	F2=	78.50	F3=	80.27	F4=	51.29	F4=	66.55

4. Discussion

The initial list of RFs that affect the OGPs was identified based on the literature review and it was evacuated via a questionnaire survey. The participants were asked to add RFs that have not mentioned in the survey. After analysing their comments, the list of the affective RFs was revised. For instance, some of the RFs have been deleted from the list like the hacker attacks on the operating or control system and animals' accidents as these RFs have a very low impact on the OGPs in Iraq based on the results of the survey. Some of the RFs like construction and material defects were split up into three RFs, which are design defects, construction defects and material defects. Some of the RFs were merged as one RFs like geographical location like "insecure areas" and the pipeline is easy to access. Some of the RFs added to the list like the pipes are older than the design age. Table 3 shows the final lists of RFs by their type.

Table 3. The final lists of RFs by their type.

Groups	The RFs before the survey	The RFs after the survey	RF number
Security and Safety (S&S)	Terrorism and sabotage	Terrorism, sabotage and the security	1
	Thieves	Thieves	2
	Public's Low legal and moral	Public's Low legal and moral awareness	3
	Staff threats	*Deleted*	
	Socio-political such as poverty and	Socio-political effects such as poverty and	4
	Leakage of sensitive information	Leakage of sensitive information	5
Rules and Regulations (R&R)	Corruption	Corruption	6
	The law does not apply on the	The law does not apply on the saboteurs	7
	Stakeholders are not paying proper attention	Not paying proper attention to risk management (e.g. not following scheduled	8
	Lack of proper training	Lack of proper training	9
	Lack of the accidents database and	Lack of the accidents database and	10
	Limited researchers about this	Limited researchers about this subject	11
Pipeline Location (PL)	Geographical location like	Geographical location e.g. insecure zones	12
	The pipeline is easy to access	*Deleted*	
	Conflicts over land ownership	Conflicts over land ownership	13
	Geological risks such as	Geological risks such as groundwater and	14
	Vehicles accidents	*Deleted*	
	Animals attacks on the pipeline	*Deleted*	
Health Safety and Environment (HSE)	Improper safety regulations	Improper safety regulations	15
	Improper inspection and	Improper inspection and maintenance	16
	The above-the-ground pipeline increases sabotage and thefts	The above-the-ground pipeline increases sabotage and thefts opportunities	17
	Limited warning signs	*Deleted*	
	Inadequate risk management	*Deleted*	
	Natural disasters and weather	Natural disasters and weather conditions	18
Operations Consent (OC)	Corrosion and lack of corrosive	Corrosion and lack of corrosive protection	19
	The weak ability to identify and	The weak ability to identify and monitor the	20
	Shortage of the IT services and	Shortage of the IT services and modern	21
	Design, construction and material defects	Construction defects (e.g. welding defects and damage the pipes during the	22
		Design defects	23
	Operational errors	Operational errors	24
	Hacker attacks on the operating or	*Deleted*	
The added RFs after the survey		The unqualified staff, lack of experience and not well educated about risk	25
		Pumping more than one type of petroleum product and crude oil from different fields	26
		Salts and metals contents in the transported	27
		External oil spots that negatively affect the	28
		Not taking the future urban planning into	29
		Poor quality pipes and material defects	30
		The pipes are older than the design age	31

5. Conclusion

- The developed risk assessment tool in this paper provides a systematic approach of choosing safe routes for OGP projects, specifically for the organisations that just began analysing the RFs in OGPs more effectively, which is the case in OGP projects in Iraq.
- Using the FIS in risk assessment remedies the problems of the traditional approaches to risk analysis and ranking.
- It was found in Table 2 that Route 3 is the riskiest route (F3 =80). Meanwhile, Route 4 is the safest route (F = 51). Therefore, the export gas pipeline should be built on this route.
- The initial list of the RFs has been identified from the literature review. This list has been revised after the survey based on analysing the participants' comments about adding the RFs that affect the safety of OGPs in Iraq and did not mention in the survey.
- The future work of this paper is to estimate the consequences of OGPs failures. Moreover, evaluate the cost and time impact of the RFs; as well as, the cost and time impact of the risk mitigation methods that should be applied to mitigate them.
- The future work also includes analysing the probability, severity and RI of the added RFs. As well as, investigating their impact in the pipelines' routes.

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Appendix A

Table 4: Questionnaire design (example)

RFs	What is the probability scale that the RFs threating the OGPs?					What is the severity scale of the flowing RFs?				
	Rare	**Unlikely**	**Possible**	**Likely**	**Almost Certain**	**Negligible**	**Minor**	**Moderate**	**Major**	**Catastrophi**
Terrorism and sabotage										
Thieves										
Public's Low legal and moral										
Staff threats										
Socio-political such as poverty and education										

Appendix B

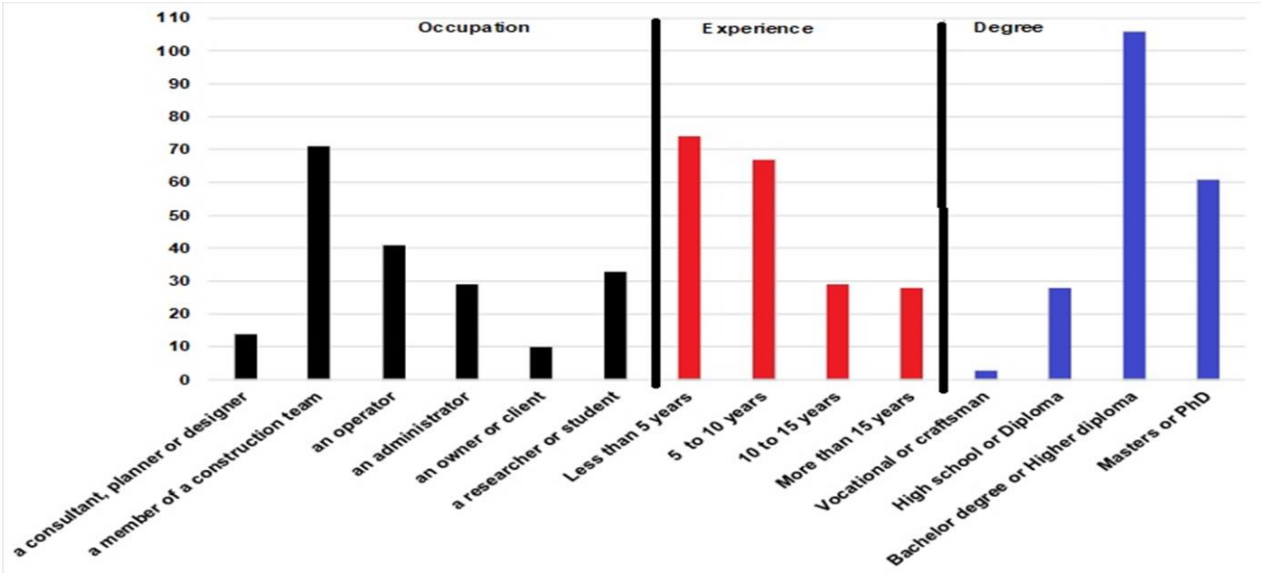

Figure 3. Participants' information.

The response rate was 199 out of 400 (49.75%).