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Risk Assessment and Mitigation Model for Overseas Steel-Plant Project Investment with Analytic Hierarchy Process—Fuzzy Inference System

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Abstract: This paper presents an analytic hierarchy process (AHP)-fuzzy inference system (FIS) model to aid decision-makers in the risk assessment and mitigation of overseas steel-plant projects. Through a thorough literature review, the authors identified 57 risks associated with international steel construction, operation, and transference of new technologies. Pairwise comparisons of all 57 risks by 14 subject-matter experts resulted in a relative weighting. Furthermore, to mitigate human subjectivity, vagueness, and uncertainty, a fuzzy analysis based on the findings of two case studies was performed. From these combined analyses, weighted individual risk soring resulted in the following top five most impactful international steel project risks: procurement of raw materials; design errors and omissions; conditions of raw materials; technology spill prevention plan; investment cost and poor plant availability and performance. Risk mitigation measures are also presented, and risk scores are re-assessed through the AHP-FIS analysis model depicting an overall project risk score reduction. The model presented is a useful tool for industry performing steel project risk assessments. It also provides decision-makers with a better understanding of the criticality of risks that are likely to occur on international steel projects.

Keywords: Natural resource development; Risk assessment and mitigation; Analytic Hierarchy Process (AHP); Fuzzy Inference System (FIS); steel plant; Investment Sustainability; Engineer Procure and Construct (EPC)

1. Introduction

Given the moderate recovery in the global economy and steel demand, and the adjustment of supply through the retirement of aging facilities and mergers and reorganizations, global demand for new investments in steel is expected to increase. Thus, the market is ripe for overseas steel-plant investments. However, said investments come with significant risks due to increasing environmental restrictions worldwide, new steel production and processes, and the inherent unknowns of entering an international market (versus domestic) [1]. This study seeks to aid future international steel production investments to identify potential risks and their priority through an exhaustive literature review, survey of subject-matter experts, two case studies, and an analytic hierarchy process (AHP) using the fuzzy inference system (FIS).

The steel industry produces many environmental pollutants along with high energy consumption requirements. Globally, countries are implementing stricter environmental policies which current steel processes will likely not be able to meet in the near future [2]. In addition to these environmental and energy consumption problems, new steel technologies are being developed to improve existing steel processes [3–7]. The inherent challenges of executing projects internationally, compounded by both the execution and exportation new technologies, equates to executing steel-plant construction overseas an activity riddled with uncertainties and risk [8]. To increase the project success rate and to minimize trial and error in using new technologies in overseas steel production investments, this study develops a model to analyze and evaluate the relevant risks.

1.1. Existing Literature

Although most literature dedicated to the steel manufacturing process has been on improving the efficiencies of the production process (e.g., [3–7]), as early as 1985, investigations were taking place on the effect uncertainty has on the steel industry and associated investments [9]. Min [1], Price et al. [10], and Bucur et al. [11] have all investigated uncertainties in steel manufacturing from a global perspective. They presented optimized steelmaking processes and technologies to overcome the loss of profitability caused by an oversupply of steel mills [1,10] and identified a correlation between global economic growth, car production, and steel manufacturing [11]. Other studies have identified uncertainties in steelmaking at the plant level. Zhang [12] presented a model of China's iron and steel industry risk factors based on resource ecological economics and eco-industry theory. De Magalhães Ozorio et al. [13] included uncertainty in assessing steel manufacturing plant processes and layouts and the profitability of the associated required investments. Kaushal [14] discussed the risk experiences on a failed Korean-led steel plant meant for Orissa, India. To mitigate the impacts that these risks have on cash-flow fluctuations, Kim et al. [15] developed a two-color rainbow options valuation to optimize the investment timing on a hypothetical steel plant. Mali and Dube [8] and Lee [16] have performed risk analysis specifically pertaining to the topic of this paper and are two publications this paper most significantly builds from. Mali and Dube [8] presented a risk register for steel-plant construction, ranking the risks based on their probability, impact, and detectability scores. The register and rankings were based on the case study findings of the construction and operation of a steel plant in India [8]. Lee [16] investigated the project definition rating index (PDRI) theory, developed by Gibson and Dumont [17] for industrial projects, identifying the most impactful early planning activities for overseas construction.

From a more general prospective, there has been a significant amount of literature on the risks associated with overseas construction and technology transfer. Many of these have been performed through an assessment of surveys, interviews, and/or case studies. Shen et al. [18] performed risk analysis on international joint venture investments, ranking the risks based on averages obtained through surveys of subject-matter experts. El-Sayegh [19] identified and assessed risks experienced in the United Arab Emirates construction industry through a questionnaire distributed to construction experts. Transitioning to technology transfer, Mansfield [20] discussed costs and potential problems related to technology transfer. Future studies built on this, presenting the risks of international licensing and investment [21]; risks of entry into foreign markets based on product exports, licensing, joint ventures, and subsidiaries [22]; and risks specifically experienced by the company providing the technology to the overseas entity [23].

Modelling tools have also been used to assess overseas construction and technology transfer risks. One of the more frequently used modelling tools has been fuzzy-logic-based methods due to their appropriateness to address uncertainty and subjectivity in decision-making processes [24]. FIS and/or fuzzy-AHP analysis have been used to rank water quality indicators [24], aid in environmental management decision-making [25,26], assess the quality and sustainability of supply chains [27–30], evaluate manufacturing processes [31], manage investment portfolios [32], provide the appropriate healthcare services for senior citizens [33], optimize the liquefied natural gas importation in Korea [34], optimize robot path selections of mobile robots [35], optimize joint distribution alliance partnerships [36], assess emerging three-dimensional integrated circuit technologies [37], assess potassium saturation of calcareous soils [38], evaluate the land suitability for a multitude of purposes [39], evaluate barriers of corporate social responsibility [40], and aid a multitude of other decision-making processes. Concerning the risks of technology transfer, fuzzy analysis was used to aid technology-based decisions for information technology organizations competing in global markets [41] and in transferring biotechnology [42].

Fuzzy analysis was specifically found to be a viable technology for modelling, assessing, and managing global risk factors affecting construction performance [43]. To that end, the fuzzy and/or AHP method has been used to assess construction projects based on sustainable development criteria [44], improve the efficiency of contractor bidding decisions [45,46], assess e-procurement outsourcing risks [47,48], evaluate the risk of bridge structure failure [49], and aid owners in selecting the best contractor [50,51]. They have been used for general risk assessment of overseas construction projects [52] and for more specific project types such as the build-operate-transfer project delivery model [53]. Fuzzy analysis has been used to in contract management, ranking which risks the owner and contractor could most effectively manage [54]. Tah and Carr [55], Carr and Tah [56], and Abdelgawad and Fayek [57] all used fuzzy analysis to assess the most common risks, their relative impact and probability of occurrence, and correlation to project performance on different types of construction projects. Karimi Azari et al. used fuzzy analysis to develop a tool to aid contractors and owners in selecting the most appropriate risk assessment model for their given project [58]. More closely related to steel manufacturing, fuzzy analysis has been used to identify and rank risks for power plant construction [59] and in choosing the optimal technologies to be used for a manufacturing plant [60,61].

1.2. Point of Departure and Research Motivation

While there exists a significant amount of research dedicated to the assessment of different types of constructing projects internationally, there has been very little research specifically related to international steel projects. The authors only found one publication that discusses risks associated with steel project construction and operation, focused on domestic steel-plant production and operation within India [8]. This publication identified and ranked 11 development risks, 12 pre-construction risks, 71 construction risks, 14 operational risks, 15 transfer of termination risks associated with one Indian steel plant [8]. While an impactful publication, the data collection was isolated to a singular project limiting its applicability. This paper contributes to the existing body of knowledge by building from Mali and Dube's [8] findings, increasing the applicability through a more rigorous research methodology (AHP and FIS) and robust data collection (14 international subject-matter experts). Because there are few projects within this area, fuzzy analysis is one of the more effective methods of translating human vagueness into quantifiable risk impacts [43].

The overall motivation of this study is to aid international steel production sponsors and managers in their early project planning risk assessments. The findings of this study will provide these early decision-makers a general list of the most impactful risks expected to be experienced on international steel production projects. Furthermore, the research methodology and examples provide a process for risk assessment to be potentially replicated within the steel industry.

2. Research Methodology and Data Collection

To identify and rank overseas steel investment risks, the authors followed the internationally recognized Project Management Body of Knowledge (PMBOK) project risk management process. This includes the following four steps: identify risks, qualitative risk analysis, quantitative risk analysis, and plan risk response [62]. The research methodology, as it fits within these four steps, is illustrated in Figure 1, and presented in greater detail within the following pages.

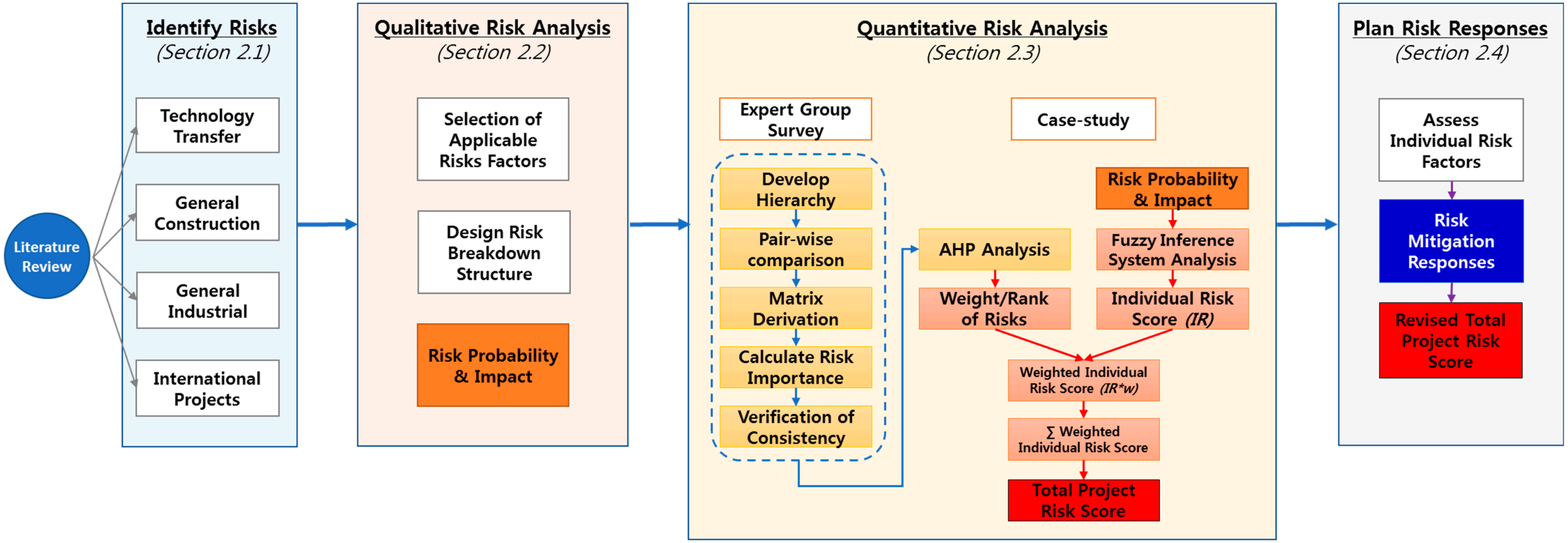

Figure 1. Research Methodology.

2.1. Risk Identification

To identify all potential risks in planning, constructing, and operating an overseas steel-plant investment, the authors reviewed existing literature focusing on technology transfer, construction, and international projects. Risks associated with the transference of technology came from Park's [23] proposed checklist evaluating overseas technology transference through licensing, from the perspective of the technology provider. General construction risks were pulled from Lee's [16] identification of 30 external and 36 internal risk factors associated with international construction. General industrial risks came from Gibson and Dumont's [16] PDRI which lists the 70 most impactful construction, operation, and maintenance planning elements. Finally, Osland et al.'s [22] identified risk factors associated with entering or expanding into an international market were also compiled. From these publications, 164 risks were identified. The authors chose 57 risks applicable to steel-plant technology and overseas construction and operation, defined in greater detail below.

2.2. Qualitative Risk Analysis

The authors developed a risk breakdown structure (RBS) hierarchy, reducing the 164 risks identified through the literature review to 57 risks applicable to overseas steel-plant project execution. This reduction was made based on previous experience of the authors, performed by a Korean Pohang Iron and Steel Company (POSCO) Senior Manager with 17 years of steel-plant experience, with guidance via informal interviews of several POSCO employees. The resultant RBS hierarchy went from Level 1 to Level 3. Level 1 are broad risk definitions, broken into four categories: the project's external environment (R1), project feasibility and plan (R2), contract (R3), and EPC (R4). Level 2 consists of more defined areas of risk and Level 3 are the actual risks identified for assessment. The RBS can be seen below in Tables 1–4.

Table 1. Risk Factors of Project External Environment (R1) [16,22,23].

Level 1	Level 2		Level 3	
R1 Project External Environment	R11	Characteristics of local government	R111	Business practices and consistency of laws and policies
			R112	Local government regulations on the industry
			R113	Need for localization
	R12	Economy, market situation	R121	The economic situation of the country to be promoted
			R122	Changes in economic indicators (exchange rate, inflation rate, interest rate, etc.)
			R123	Market demand for the target product and competition
			R124	Downstream industry and material prices volatility
	R13	Social and cultural characteristics	R131	Social stability
			R132	Characteristics of local labor force
			R133	Cultural feature
			R134	Local awareness of the project
	R14	Geography/Climate and infrastructure conditions	R141	Climate characteristics
			R142	Characteristics of soil
			R143	Distance from home country
			R144	Status and plans of Infrastructure and utility
	R15	Legal standards (regulations)	R151	Legal standards of design and licensing criteria
			R152	Tariff standard
			R153	Environmental regulations
			R154	Procedures and criteria for repatriation of profits
			R155	Regulations on transfer of technology in home country

Table 2. Risk Factors of Project Feasibility and Planning (R2) [16,22,23].

Level 1	Level 2		Level 3	
R2 Project Feasibility and Planning	R21	Members of the project	R211	Characteristics of a local joint venture
			R212	Capabilities of sub-contractor and material supplier
			R213	Features of lender (requirements)
	R22	Coal, raw materials, coke	R221	Conditions of coal, ore, and raw materials
			R222	Procurement plan of coal, ore, and raw materials
	R23	Scope and requirements for completion of the Project	R231	Characteristics (process composition) and capacity of target product
			R232	Schedule of the project
			R233	Suitability and validity of the applied process and technology
			R234	Documents and outputs related to the project
			R235	Performance requirements
	R24	Economics (profitability)	R241	Investment costs
			R242	Operating expenses
			R243	Revenue (product sales and prices)
			R244	Financing plan
			R245	Components and scale of license fees

Table 3. Risk Factors of Project Contract (R3) [16,22,23].

Level 1	Level 2		Level 3	
R3 Project Contract	R31	Clarity of contract	R311	Experience with similar contracts
			R312	Clarification of criteria on LD (liquidated damages)
			R313	Ambiguous contract terms (imperfection)
			R314	Specification of force majeure
	R32	License contract	R321	Infringement of intellectual property rights of third parties
			R322	Prohibition of license transfer
	R33	Technology protection	R331	Technology spill prevention plan
			R332	Excessive requirements on the joint venture (or licensee) related to the technology
			R333	Access to operational records and ownership of developed technologies after completion
	R34	O&M contract	R341	Excessive O&M expenses
			R342	Poor plant availability and performance

O&M = Operation and Maintenance.

Table 4. Risk Factors of EPC (R4) [16,22,23].

Level 1	Level 2		Level 3	
R4 EPC	R41	Engineering	R411	Construction/Complexity
			R412	Specification of major equipment
			R413	Timeliness of design
			R414	Design faults (errors) and omissions
	R42	Procurement	R421	Manpower procurement plan
			R422	Procurement plan of major equipment
	R43	Construction	R431	Selection of suitable construction method
			R432	Transportation and quality assurance of construction materials and equipment
			R433	Collaboration with partners and local businesses
			R434	Worker's safety management and construction safety facility

2.3. Quantitative Risk Analysis

The relative importance of the above risk factors was identified through questionnaires answered by subject-matter experts. Questionnaires are conducted through pairwise comparisons between risk factors in the group for each level. Figure 2 is an example of a portion of the questionnaire, representing the R13 risk factor group at Level 3. Fourteen (14) industry experts were chosen with the following qualifications: expert with new steelmaking processes such as Financial Instruments Exchange and/or Compact Endless Cast [1] and a minimum of 10 years of experience in project management for steel, construction, and/or heavy industry. This equated to the questionnaire being answered by nine steel and five general overseas investment subject-matter experts.

Risk Factor : Social and cultural characteristics		
Lower level's risk factor		**Contents**
①	**Social stability**	- Distribution of wealth, Population density - Factors related to social conflict
②	**Characteristics of local labor force**	- Productivity of labor, Laborer's probity, Language barrier
③	**Cultural feature**	- Ethical, Religious dispute - Protectionism
④	**Local awareness of the project**	- Demonstration and Dispute against the project - Civil complaint and demand for reward

Risk Factor	Extremely More Important								Equally Important								Extremely More Important	Risk Factor
① Social stability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	② Characteristics of local labor force
① Social stability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	③ Cultural feature
① Social stability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	④ Local awareness of the project
② Characteristics of local labor force	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	③ Cultural feature
② Characteristics of local labor force	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	④ Local awareness of the project
③ Cultural feature	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	④ Local awareness of the project

Figure 2. Pairwise Comparison Survey Example (R13).

From the data collected from the questionnaires, the authors performed an AHP analysis. Figure 1 shows the five steps involved in an AHP analysis: develop a hierarchy, perform a pairwise comparison, derive the matrix, calculate risk importance for each element, and verification of consistency. The hierarchy developed is represented by Tables 1–4 risks. Subject-matter experts (nine steel and five general overseas investment described in greater detail above) performed a pairwise comparison by comparing and scoring risk factors. An example survey sent for Risk R13 is shown in Figure 2. As can be seen, the authors used the 1–9 scale [63] to have the subject-matter experts compare differing risks. 1 represents that the risk factors being compared are of equal importance and 9 represents one of the risk factors being extremely more important than the other. This is performed "n" times until all alternatives are compared and, from these values, a pair comparison matrix is constructed. The survey results are aggregated via the geometric mean method to creating a single vector which represents the combined responses [64]. Assuming the expert filled out the example Figure 2 questionnaire with all 9s, the matrix would appear as follows [65]:

$$A = \begin{vmatrix} 1 & \dots & \dots & a_{1n} \\ \dots & 1 & a_{ij} & \dots \\ \dots & a_{ji} & 1 & \dots \\ a_{n1} & \dots & \dots & 1 \end{vmatrix} = \begin{vmatrix} 1 & 9 & 9 & 9 \\ \frac{1}{9} & 1 & 9 & 9 \\ \frac{1}{9} & \frac{1}{9} & 1 & 9 \\ \frac{1}{9} & \frac{1}{9} & \frac{1}{9} & 1 \end{vmatrix} \quad (1)$$

where A is the pairwise comparison matrix and a_{ji} is the comparison between i and j and $a_{ji} = \frac{1}{a_{ij}}$.

To interpret and give relative weights to each risk (calculate importance of each element), it is necessary to normalize the comparison matrix (matrix derivation). This is performed with three equations (shown below using the example from Figure 2) [65]:

Sum the elements of each column:

$$\begin{aligned} A &= \begin{vmatrix} 1 & 9 & 9 & 9 \\ \frac{1}{9} & 1 & 9 & 9 \\ \frac{1}{9} & \frac{1}{9} & 1 & 9 \\ \frac{1}{9} & \frac{1}{9} & \frac{1}{9} & 1 \end{vmatrix} \\ P &= \quad 1.33 \quad 10.22 \quad 19.11 \quad 28 \end{aligned} \quad (2)$$

Divide each value by its column sum:

$$A = \begin{vmatrix} \frac{1}{1.33} & \frac{9}{10.22} & \frac{9}{19.11} & \frac{9}{28} \\ \frac{0.11}{1.33} & \frac{1}{10.22} & \frac{9}{19.11} & \frac{9}{28} \\ \frac{0.11}{1.33} & \frac{0.11}{10.22} & \frac{1}{19.11} & \frac{9}{28} \\ \frac{0.11}{1.33} & \frac{0.11}{10.22} & \frac{0.11}{19.11} & \frac{9}{28} \end{vmatrix} \tag{3}$$

Mean of Each Row:

$$A = \begin{vmatrix} \frac{1}{1.33} & \frac{9}{10.22} & \frac{9}{19.11} & \frac{9}{28} \\ \frac{0.11}{1.33} & \frac{1}{10.22} & \frac{9}{19.11} & \frac{9}{28} \\ \frac{0.11}{1.33} & \frac{0.11}{10.22} & \frac{1}{19.11} & \frac{9}{28} \\ \frac{0.11}{1.33} & \frac{0.11}{10.22} & \frac{0.11}{19.11} & \frac{9}{28} \end{vmatrix} = \lambda = \begin{vmatrix} \mu_1 = 0.605 \\ \mu_2 = 0.243 \\ \mu_3 = 0.117 \\ \mu_4 = 0.034 \end{vmatrix} \tag{4}$$

where A is the pairwise comparison matrix, P is the priorities vector, λ is the eigenvector, and μ_n is the average for row "n" and weight of the factor (risk importance).

As the number of elements increases, the number of pairwise comparisons increases, which can result in poor concentration and error in judgment or inconsistent matrices [66]. As the weights of the factors (risk importance) only makes sense if derived from consistent matrices, a consistency check must be applied [65]. The consistency ratio (CR) is an indicator of the degree of error or contradiction of decision-makers, calculated through the following equations:

$$\text{Consistency Index (CI)} = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

where, $\lambda_{max} = \lambda * P$ and is the max eigenvalue of matrix, and n is the number of evaluated criteria.

$$\text{CR} = \frac{CI}{RI} \tag{6}$$

where, RI is the random consistency index and is a fixed value (values pulled from [67]).

If the value of CR is less than 10%, then the pairwise comparison matrix has acceptable consistency. There are two types of consistency. One is ordinal consistency and the other is cardinal consistency. Ordinal consistency (transitivity) means that when there are A, B, and C comparisons, if A is more important than B and B is more important than C, then A must be more important than C. Cardinal consistency means that if A is p times more important than B and B is q times more important than C, A should be p*q times more important than C. If a decision maker satisfies the cardinal consistency, the ordinal consistency is also satisfied, but satisfying the ordinal consistency does not guarantee that the cardinal consistency is satisfied [68].

The survey resultant data was assessed by Matrix Laboratory (MATLAB, developed by MathWorks U.S.) for consistency verification and weighting of the responses of the questionnaire. Consistency tests showed that CR in some responses exceeded 10%. Saaty [63] states, in general, human beings cannot accurately maintain cardinal consistency in AHP because they cannot make accurate measurements of intangibles. It is difficult to judge human thoughts, feelings, and preferences when people try to maintain cardinal consistency [63]. Therefore, the responses with CR of 10% or more were classified into two types. If the response does not satisfy the ordinal consistency, a new judgment is required for the part that does not satisfy the transitive feature of the respondent. If the CR of the response exceeds 10% and does not satisfy the cardinal consistency, the original value is used to reflect the vagueness or uncertainty of the respondent's subjective judgment.

Next, the authors used the data from two case study projects, descriptions shown in Table 5 to perform a FIS analysis.

Table 5. Details of Case Study Projects.

	Project A	Project B
Country	China	Iran
Company	National Steel Company	Trading company
Project	3 million tons of integrated steel mill using new steel technology	3 million tons of integrated steel mill using new steel technology
Financing	Equity to Debt = 40:60 Technology provider to Acquirer = 49:51	Equity to Debt = 30:70 Technology provider to Acquirer = 20:80
Features	Demand for steel in the region is expected to increase due to Western development strategies. Eco-friendly steel mill with new technology is established in accordance with the government's environmental regulations	New investments are made in steel plants as economic sanctions are lifted. Local abundant natural gas can be used

From the two case studies, each of the 57 were given a linguistic value to their degree of influence and likelihood of occurrence rated as one of five intensities: very low, low, medium, high, or very high. The resultant data falls on a risk probability-impact matrix or heat map seen below in Table 6.

Table 6. Risk Probability-Impact Matrix.

Likelihood of Occurrence \ Degree of Influence	VL	L	M	H	VH
VL	VL	VL	L	M	M
L	VL	L	M	M	H
M	L	M	M	H	VH
H	M	M	H	VH	VH
VH	M	H	VH	VH	VH

VL: very low; L: low; M: medium; H: high; VH: very high.

The linguistic variable impact was then used as an input to the MATLAB FIS tool [69] for evaluating all the individual risk scores for the case study projects. The MATLAB tool uses the Mamdani FIS method. The basic standard operations were used for AND and OR operations. The fuzzification interface was set to min, and aggregation on output was set to max. For defuzzification, the centroid method was used so that the risk could be evaluated at the most appropriate level. In this study, because MATLAB was used in the overall process of FIS, Gaussian type membership functions that best described actual phenomena were used as input and output membership functions, shown below:

$$f(x;\sigma,c) = e^{\frac{-(x-c)^2}{2\sigma^2}} \quad (7)$$

where, f(x; σ, c) is the membership function, plotted in Figure 3 below; x is the impact value given to the risk based on Table 6 and the MATLAB FIS tool [69], c is the center value as shown in Table 7 (linguistic variable derived from Table 6), and σ is a constant value of 10.5 per the Gaussian membership function (MF).

Table 7. Linguistic Variable and Membership Function Parameter.

Linguistic Variable	Gaussian MF Parameter Center (c)	Gaussian MF Parameter Sigma (σ)
Very Low	0	10.5
Low	25	
Medium	50	
High	75	
Very High	100	

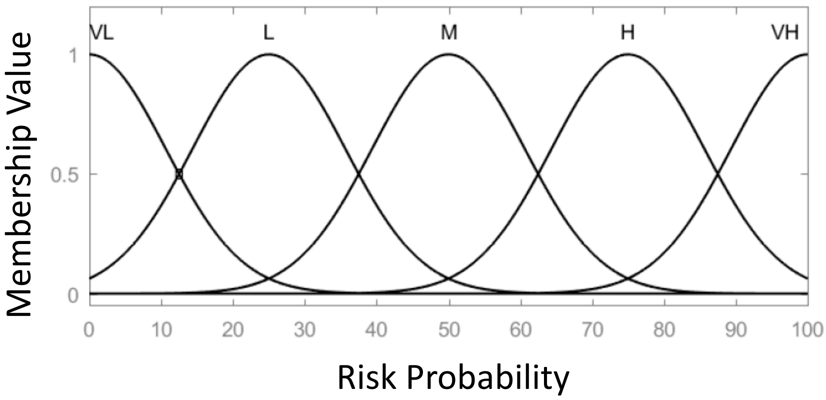

Figure 3. Membership Function.

From the risk impact (Table 6) and probability (Equation (7)), the MATLAB FIS tool [68] assigned each of the 57 Level 3 risk factors a valuation, or individual risk score, on a scale of 0 to 100 points. As seen in Figure 4, the AHP weighted values and FIS individual risk scores are multiplied to achieve a final AHP-FIS weighted individual risk score. These individual risk scores are then summed to equate to a final project risk score which can be used to understand the overall "riskiness" of the project on a scale of 0 to 100.

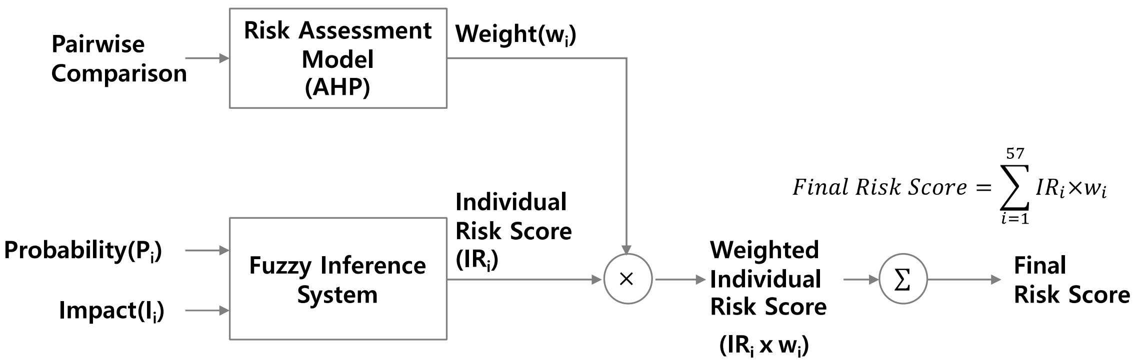

Figure 4. Final Risk Scoring Flow Diagram.

2.4. Plan Risk Responses

The output of the qualitative risk analysis step, above, is a ranking of all the risks per their weighted individual risk score. From the case study, risk mitigation measures are applied to the top five risks, reducing their impact (influence and/or likelihood of occurrence) thus reducing their individual risk score. As such, the authors then calculated a revised project risk score to understand the impact the mitigation measures had on the overall "riskiness" of the project.

3. Findings and Discussion

3.1. Risk Analysis Results

Table 8, below, shows the weights and rankings of the Level 1 and 2 risk factors from the AHP analysis. As can be seen, project feasibility and planning and the economics or profitability risks are the highest ranked.

Table 9 shows the resultant 12 most important items among the 57 risk factors of Level 3 from the AHP analysis. As can be seen the most impactful risks are procurement issues, design errors and omissions, poor plant performance, technology issues, contract issues, and revenue. In comparison, Mali and Dube [8] found Table 9 risks to rank as follows: non-availability of material ranked 14 of 120, change in design as 50 of 120, operating efficiency as 8 of 120, no discussion of technology transfer, contract disputes as 15 of 120, and no specific discussion of revenue but market price was 3 of 120. Mali and Dube's risk register is based on opinions of three site-team members versus previous literature. Unfortunately, this has led to the inability to affectively compare this paper's risk findings and theirs.

Table 10 depicts the top 12 ranked risks after the AHP-FIS analysis. As can be seen, the top 12 rankings are very similar to those found via the AHP analysis alone. However, some differences do exist. In project A, the risk of the possibility of using iron ore and coal from China for new steel technology emerged. Furthermore, the concerns for risk of technology leakage owing to imitation in China were high, and the competitiveness for investment cost by the Korean steel makers was low due to comparison with the relatively low investment cost of blast furnaces in China. The reliability and procurement plans of Chinese-made facilities to reduce investment costs were higher than those in the initial importance ranking. In the case of project B, the risk of performance of the plant using new technology with natural gas emerged. In addition, the risk of the financing plan was high because of the political instability in Iran. Similar to project A, items such as coal, ore and raw materials procurement plans and conditions, investment costs, and technical security were the top priorities.

Table 8. Weights and Rankings of Risk Factors in Level 1 and Level 2.

	Level 1	Weight	Rank		Level 2	Local Weight	Global Weight	Rank
R1	Project External Environment	0.194	4	R11	Characteristics of local government	0.26	4.99	10
				R12	Economy, market situation	0.20	3.97	14
				R13	Social and cultural characteristics	0.11	2.20	16
				R14	Geography/Climate and infrastructure conditions	0.17	3.30	15
				R15	Legal standards (regulations)	0.26	4.96	11
R2	Project Feasibility and Planning	0.284	1	R21	Project stakeholder	0.14	4.03	13
				R22	Coal, ore, and raw materials	0.27	7.54	6
				R23	Scope and requirements for completion of the Project	0.19	5.37	8
				R24	Economics (profitability)	0.40	11.47	1
R3	Contract	0.278	2	R31	Clarity of contract	0.34	9.43	3
				R32	License contract	0.20	5.64	7
				R33	Technology protection	0.28	7.71	5
				R34	O&M contract	0.18	5.00	9
R4	EPC	0.244	3	R41	Engineering	0.44	10.68	2
				R42	Procurement	0.19	4.75	12
				R43	Construction	0.37	8.97	4

Table 9. Table 9. Top 12 Level 3 Risk Factors.

Rank	Weight	Risk factor (Level 3)
2	4.75	Design faults (errors) and omissions
3	3.75	Poor plant availability and performance
4	3.22	Access to operational records and ownership of developed technologies after completion
5	3.04	Technology spill prevention plan
6	3.02	Ambiguous contract terms (imperfection)
7	3.02	Clarification of criteria on LD (liquidated damages)
8	2.91	Investment costs
9	2.88	Infringement of intellectual property rights by third parties
10	2.79	Revenue (product sales and prices)
11	2.76	Prohibition of license transfer
12	2.7	Conditions for coal, ore, and raw materials

Table 10. Top Risk Factors for Case Study Projects.

Rank	Initial Rank by Priority	Project A	Project B
1	Procurement plan of coal, ore, and raw materials	Procurement plan of coal, ore, and raw materials	Procurement plan of coal, ore, and raw materials
2	Design faults (errors) and omissions	Design faults (errors) and omissions	Design faults (errors) and omissions
3	Poor plant availability and performance	Conditions for coal, ore, and raw materials	Poor plant availability and performance
4	Access to operational records and ownership of developed technologies after completion	Technology spill prevention plan	Conditions for coal, ore, and raw materials
5	Technology spill prevention plan	Investment cost	Investment cost
6	Ambiguous contract terms (imperfection)	Ambiguous contract terms (imperfection)	Ambiguous contract terms (imperfection)
7	Clarification of criteria on LD (liquidated damages)	Clarification of criteria on LD (liquidated damages)	Clarification of criteria on LD (liquidated damages)
8	Investment cost	Poor plant availability and performance	Financing plan
9	Infringement of intellectual property rights by third parties	Access to operational records and ownership of developed technologies after completion	Technology spill prevention plan
10	Revenue (product sales and prices)	Specification of major equipment	Specification of major equipment
11	Prohibition of license transfer	Procurement plan of major equipment	Procurement plan of major equipment
12	Conditions for coal, ore and raw materials	Requirements for preliminary commissioning and takeover	Revenue (product sales and prices)

3.2. Proposed Risk Mitigation Measures

Table 11 shows the risk mitigation measures proposed for the top five risk factors as developed through the two case studies. As can be seen, most of the mitigation measures are better education and/or more a thorough early project planning.

Upon applying these risk mitigation responses, a follow-up AHP-FIS analysis was performed. With risk mitigations applied, it would be expected that the risk scores for the top five risks (and therefore for the projects as a whole) should lower. The expected decrease did occur and, as a result of applying the responses, the risk score decreased from 72.9702 to 66.9258 in the case of project A and from 70.0003 to 64.4484 in the case of project B. The order and items of the top five risk factors also changed, as shown in Tables 12 and 13. Along with planning a risk response, this represents the PMBOK risk assessment steps of implementing risk responses and monitoring results [62].

Table 11. Responses to Top Risk Factors.

Risk Factor	Response Mitigation Measures
Procurement plan of coal, ore, and raw materials	Understanding the status of available raw materials Review of location and logistics Review of feedstock supply agreement strategy
Design faults (errors) and omissions	Creation of design output checklist Sharing design output by discipline and reinforcement of crosschecks Strengthening communication with local companies
Conditions of coal, ore, and raw materials	Preliminary review and test of locally procured coal, ore, and raw materials
Technology spill prevention plan	Packaging design output and sharing only final output Adjustment of scope of project output at contract
Investment cost	Adjustment of project scope Optimization of equipment and design Localization of equipment and design Estimating the preliminary cost considering fluctuation such as exchange rates
Poor plant availability and performance	Documentation of O&M techniques for existing plant Improvement in availability and performance at the design stage Configuration and application of proven facilities

Table 12. Risk Factors after Risk Response in Project A.

Risk Rank	1st Risk Assessment 72.9702/100	Weight	Score	2nd Risk Assessment (After Response) 66.9258/100	Weight	Score
1	Procurement plan of coal, ore, and raw materials	4.85	4.86	Procurement plan of coal, ore, and raw materials	4.85	2.62
2	Design faults (errors) and omissions	4.75	3.69	Technology spill prevention plan	3.04	2.50
3	Conditions of coal, ore and raw materials	2.70	3.10	Ambiguous contract terms (imperfection)	3.02	2.44
4	Technology spill prevention plan	3.04	2.71	Design faults (errors) and omissions	4.75	2.30
5	Investment cost	2.91	2.58	Clarification of criteria on LD (Liquidated damages)	3.02	2.30

Table 13. Risk Factors after Risk Response in Project B.

Risk Score	1st Risk Assessment 70.0003/100	Weight	Score	2nd Risk Assessment (After Response) 64.4484/100	Weight	Score
1	Procurement plan of coal, ore, and raw materials	4.85	3.77	Ambiguous contract terms (imperfection)	3.02	2.43
2	Design faults (errors) and omissions	4.75	2.93	Clarification of criteria on LD (Liquidated damages)	3.02	2.33
3	Poor plant availability and performance	3.75	2.69	Financing plan	2.60	2.29
4	Conditions of coal, ore and raw materials	2.70	2.53	Technology spill prevention plan	3.04	2.23
5	Investment cost	2.91	2.48	Design faults (errors) and omissions	4.75	2.02

After the risk response, in the second risk assessment, the risk score decreased by ~8.3% for project A and ~7.9% for project B. The order and items of the top five risk factors also changed. However, risk factors with high importance remained high even after reassessment. Therefore, risks with high priority should be managed consistently.

4. Discussion: Industry Implications

When a sponsor chooses to execute and finance the construction and operation of an international steel plant, it can play a variety of roles such as a licensor, material provider, operation and maintenance agency, and/or a contractor [70]. The diversity of necessary expertise and general lack of experience in international work exposes managerial teams to unknown risks with unknown magnitudes. By identifying, quantifying, and prioritizing international steel production risks through surveys and case studies of international steel production projects, this paper provides decision-makers a baseline for which to develop project-specific risk management plans. The identified risks will aid project investors in funding the project and managing the contingencies and economic fluctuations of the project. The identified risks will also aid project managers in developing and executing a risk mitigation plan, potentially increasing both the cost and schedule efficiencies of the project [62].

5. Conclusions

Presented in this paper is an AHP-FIS risk assessment model which identifies, quantitatively evaluates, and prioritized risks likely to be experienced on international steel projects. From these combined analyses, weighted individual risk soring resulted in the following top five most impactful international steel project risks: procurement of raw materials, design errors and omissions, conditions of raw materials, technology spill prevention plan, investment cost and poor plant availability and performance. While this knowledge alone is beneficial in the early planning stages of an international steel project, the process presented allows decision-makers to accurately identify risks for any given project type even when data is subjective, vague, and/or uncertain. It also includes a risk mitigation, implementation, and impact assessment cycle which will allow decision-makers to test out the effectiveness of risk mitigation strategies.

5.1. Limitations

Only negative risks are considered in this study. Opportunities, or positive risks, are not considered. This is a limitation as positive risk factors may lower the overall project final risk score and removing it from consideration reduces the efficacy of comparing project Final Risk Scores. Also, the correlations among risks are not taken into consideration. For some projects, when one risk occurs the likelihood of another risk occurring may increase or decrease. Thus, ignoring correlation reduces the accuracy of the presented model. However, this would only impact the plan risk response revised Individual and Total Risk Score portions of the process. Finally, though the process is flexible, the proposed model is not applicable to all cases of overseas new steel technology transfer. The resources and the expected profit for each case are different.

5.2. Future Research

A model should be studied in which optimal cases can be selected by considering both the risks and opportunities of a single project when performing multiple projects with limited company resources. Finally, further data, specifically on the risks associated with new steel technology transfer, are required to increase the model accuracy.

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Abbreviations

AHP	Analytic Hierarchy Process
FIS	Fuzzy inference system
EPC	Engineering Procure and Construct
PDRI	Project Definition Rating Index
PMBOK	Project Management Body of Knowledge
O&M	Operation and Maintenance
POSCO	Pohang Iron and Steel Company
RBS	Risk Breakdown Structure
MATLAB	Matrix Laboratory

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