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Analysis and assessment of the relationships between external risks affecting timelines in oil pipeline construction projects

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Abstract

The aim of this study is to analyze and evaluate the interrelationships among external risks that affect project timelines in oil pipeline construction projects in Iran, with a specific focus on the 16-inch Yazd-Naein oil pipeline construction project. External risks were identified through qualitative techniques, including checklists, expert interviews, and comparative analyses of similar projects. To evaluate risk interdependencies and establish a hierarchical structure, the Interpretive Structural Modeling (ISM) method was employed. This method highlights driving risks—those that significantly impact other risks—and dependent risks—those primarily influenced by other risks. The findings identify critical external risks that influence project timelines, including inflation, encroachment issues, exchange rate volatility, intersections with existing infrastructure, limited access to foreign suppliers, earthquake damage, and a shortage

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of specialized personnel in consulting departments. Among these risks, inflation was recognized as the most influential and independent factor. This research introduces an innovative framework for analyzing and evaluating the interdependencies among external risks affecting project timelines in oil pipeline construction projects in Iran. By addressing challenges unique to Iran, the study provides practical insights into managing uncertainties and reducing project delays while bridging critical gaps in the literature and offering tailored strategies for mitigating risks.

Keywords Interpretive Structural Modeling (ISM), MICMAC Analysis, External Risks, Project Timeline, Oil Pipeline Construction, Risk Response Strategies.

1. Introduction

Ensuring a stable and sustainable energy supply is a critical challenge worldwide, playing a key role in driving economic growth and supporting long-term development (Zafar et al., 2019). Among various energy resources, oil and gas continue to play a significant role, fulfilling a substantial portion of the world's energy demands across industrial, commercial, and domestic sectors (Rahman and Velayutham, 2020). However, concerns about the sustainability of the oil and gas sector have existed since the early days of exploration. These concerns have intensified as modern societies become more reliant on these resources (Sharif et al., 2020). Investing in oil and gas projects entails substantial risks, including technological complexities, high capital requirements, and geopolitical uncertainties (AlNoaimi & Mazzuchi, 2021; Saptarini, 2022). The oil and gas projects operates in a highly risky environment that, due to harsh operating conditions, high investments, technical complexity, and multidisciplinary collaboration, requires precise control and enhanced productivity (Majrouhi Sardroud et al., 2021). These projects are further exposed to external risks, including economic volatility, political instability, inconsistent government policies, and the escalating impacts of climate change (Adeleke et al., 2018). Mitigating these risks is essential to the success of construction projects, both upstream and downstream (De Maere d'Aertrycke et al., 2017). In developing countries, risk management is often hindered by limited resources, economic instability, and inadequate infrastructure (Serpell et al., 2015). Today, the industrial productivity of many nations heavily depends on oil—an industry exposed to environmental risks, unpredictable accidents, and human errors (Roodpeyma and Mahmoudzadeh Kani, 2023). Despite the growing adoption of risk management strategies, outdated and insufficient techniques remain widespread in the construction sector, resulting in suboptimal project outcomes and constrained overall performance (Adeleke et al., 2018, Serpell et al., 2015). Effective risk management practices are therefore essential to mitigate these challenges and enhance project success (Ahmad et al., 2022). Given Iran's ranking as the third-largest holder of global oil reserves and the second-largest in natural gas reserves, the country plays a crucial role in the global energy market, despite facing challenges such as sanctions and infrastructure limitations. With over 70% of Iran's total project value attributed to the oil and gas sector, delays in many projects highlight the importance of robust risk management (Fallahnejad, 2013, Zarei et al., 2018, Sweis et al., 2019). Managing risks associated with high-investment engineering equipment, such as oil and gas pipelines, is particularly critical (Bi et al., 2023). Buried pipelines are vital lifelines whose safe and reliable operation is essential for human life

(Salimi Firoozabad et al., 2022). Delays in these projects, especially in the oil sector, often arise due to uncertainties in scheduling, resource allocation, and environmental factors. Through advanced risk management techniques, project stakeholders can better mitigate these risks and improve project timelines and outcomes (Sandhyavitri, 2022). Effective risk management strategies, including improved communication and systematic approaches, play a vital role in preventing recurring issues in construction projects. These strategies can enhance project quality, reduce delays, and improve project timelines (Lambers et al., 2024).

This study employs a comprehensive and structured methodology to explore the relationships among external risks affecting the timelines of oil pipeline construction projects in Iran. The case study of the Yazd-Naein oil pipeline project offers a detailed analysis of these risks in a realistic and complex construction environment. Using Interpretive Structural Modelling (ISM) and cross-impact analysis methods, risks were systematically classified based on their levels of influence and dependency within the project's risk framework. The primary goal is to provide a practical framework for identifying, analyzing, prioritizing, and mitigating risks to optimize project timelines and minimize the adverse effects of external risks. In addition to addressing gaps in the literature, this study provides project managers with practical tools and clear methodologies to enhance informed and effective decision-making processes.

The innovation of this research lies in its focused and comprehensive analysis of external risks in oil pipeline construction projects, particularly within an economic and political context as distinctive as that of Iran. This study goes beyond isolated and static analyses by examining the dynamic interrelationships among risks and their cumulative effects on project scheduling—an aspect largely overlooked in prior literature. The use of Interpretive Structural Modeling (ISM) was not merely for prioritization purposes, but as a tool to identify high-impact driving risks and highly influenced dependent risks. By combining structured analysis with credible field data, this research presents a framework that is not only academically robust but also provides practical and effective solutions for managers of infrastructure projects operating under complex conditions. Furthermore, the integrated approach adopted in this study—emphasizing factors such as inflation, sanctions, and international trade restrictions—is designed to be applicable to other developing countries facing similar challenges.

2. Literature review

Risk management in construction projects is crucial for achieving project objectives while minimizing additional costs, delays, and disputes among stakeholders (A. Kassem et al., 2019, Pourdoustmohammadi and Ansari, 2024). Delays not only affect the cost and quality of a project but also trigger conflicts among involved parties. The complexity of construction projects and the numerous risks involved highlight the critical role of effective risk management (Zhao, 2023; Chen, 2022; Lin, 2021). Although it is impossible to eliminate all project risks, projects that identify, analyze, and manage risks early are generally more successful (Durugbo et al., 2020). Recent studies have significantly advanced the understanding of risk factors in construction projects, emphasizing their impact on project outcomes (Liu et al., 2016). In recent years, extensive research has been conducted on project risk, some of which are outlined below. Bin Seddeeq et al. (2019) examined the factors causing delays and cost overruns in oil and gas construction projects in Saudi Arabia. Their study identified five main causes: changes initiated by the client in design and scope, poor planning, design errors, unclear project scope during the bidding phase, and underestimation of costs and schedules, or the overestimation of benefits. The findings highlight key areas where improvements are needed to manage these factors effectively and prevent significant overruns.

Hatmoko and Khasani (2019) identified 28 risks causing delays in Engineering, Procurement, and Construction (EPC) projects through a case study of a subsea platform and pipeline in an Indonesian oil and gas project. Key risks included contractor financial issues, delays in the delivery of long-lead items, changes in the project scope, design delays, and contractor inexperience, providing valuable insights for effective risk mitigation. A. Kassem et al. (2020) investigated the impact of internal risk factors on project success in the oil and gas sector of Yemen using PLS-SEM. The study identified six key risk factors affecting project success: risks related to the client, feasibility and design, tendering, resources, contracts, consultants, and risk management. Kazemi et al. (2021) conducted a quantitative study to identify and prioritize the causes of delays in Iranian oil projects. The results revealed that the most critical factors were sanctions, government management systems, weak project management by the contractor, and financial problems. Moreover, changes in laws and regulations, inappropriate organizational structures, and fluctuations in material prices significantly contributed to project delays. Following these findings, Rawat et al. (2023) identified similar risks in urban gas distribution projects in India. They emphasized that improper project management, economic changes, and contractor issues were identified as common factors affecting project timelines and costs. Alshibani et al. (2022) identified and prioritized the main factors causing schedule delays in Saudi Arabian oil and gas pipeline construction. Of 47 potential delay factors, the five most critical were issues with client-provided materials, delays in material/equipment deliveries, permit approval delays, subcontractor delays, and holdups in engineering drawing approvals. The study stresses the importance of addressing these issues to minimize delays and enhance project performance. Fallahnejad (2013) analyzed delays in 24 gas pipeline projects in Iran, identifying 43 key factors. Major issues included reliance on imported materials, unrealistic schedules, problems with client materials, land acquisition challenges, and scope changes. The study emphasizes addressing these issues to improve project efficiency and ensure timely completion in line with Iran's strategic objectives. Sweis et al. (2019) reported the reasons for delays in Iranian oil and gas projects using root cause analysis in five categories: financial, site, operational, human and equipment, and external categories. According to the results, the operational-related category was identified as the most influential category. Suppramaniam et al. (2018) identified the causes of delays in the construction phase of Malaysian oil and gas projects and examined and categorized them into six main categories: owner, contractor, engineering, external, project, and resources. Zarei et al. (2018) used Semantic Network Analysis (SNA) to rank delay causes in oil, gas, and petrochemical projects, revealing connections often overlooked by traditional methods. The study identified key delays, including inaccurate cost estimates and lengthy approval processes, providing actionable insights for project managers to reduce delays in complex environments. Aljamee et al. (2020) examined the causes of delays in Iraqi petroleum industry projects. Key factors identified included low bidding prices accepted by contractors, financial difficulties, reliance on paper instead of software, holidays, and poor project management planning. These issues highlight areas that must be addressed to improve project timelines. Al-Gahtani et al. (2023) investigated the risk factors contributing to time and cost overruns in pipeline construction projects in Saudi Arabia. Key factors included discrepancies between execution and specifications, financial insolvency, poor material quality, and weak threat monitoring. The findings offer a framework for prioritizing risks and improving resource management. Kraidi et al. (2021) conducted a study aimed at mitigating the safety and security risks associated with oil and gas pipeline projects. Their goal was to develop a risk management system based on a comprehensive approach that includes identifying, analyzing, and ranking risk factors, as well as evaluating risk mitigation methods.

The literature highlights a significant gap in the analysis of interdependencies among external risks in oil pipeline construction projects, especially within the Iranian context, where geopolitical and economic factors further complicate risk management. Previous studies have primarily focused on identifying individual risk factors or broad categories, overlooking the complex relationships and ripple effects of external risks on project timelines. This research addresses this gap by introducing a structured framework for systematically identifying, analyzing, prioritizing, and assessing these risks. By employing advanced methodologies such as ISM, the study highlights both the direct impacts of external risks and their interconnections and cumulative effects. This approach enhances understanding of the uncertainties inherent in oil pipeline construction projects. It also offers a solid foundation for creating targeted risk mitigation strategies suited to the complexities of the Iranian construction environment.

3. Research Method

3.1 Case Study

This research focuses on the 16-inch Yazd-Naein oil pipeline construction project in Iran, spanning approximately 99 kilometers. The project included constructing the pipeline and installing key intermediate facilities, including main valves, air release valves, and cathodic protection stations, which were essential for the pipeline's operation and safety. The project was executed by the Iran Oil Pipelines and Telecommunications Company (IOPTC), which plays a central role in maintaining the stability and efficiency of Iran's energy infrastructure and supply chain. IOPTC oversees a vast network, including more than 14,000 kilometers of pipelines and 296 telecommunications stations, through which more than 128 billion liters of petroleum products are transported annually. These robust infrastructures underscore IOPTC's vital role in ensuring the stability and security of Iran’s energy supply chain. Moreover, the Yazd-Naein pipeline project aims to enhance the capacity for transporting petroleum products in the region and improve the country’s energy security, particularly considering the economic and political challenges the country faces, which significantly impact energy supply and resource access.

The Yazd–Naein oil pipeline construction project was selected as the case study for this research because it represents a prominent and generalizable example among infrastructure projects in Iran’s oil industry, both in terms of its technical and structural characteristics and its exposure to external risks. With its considerable duration, technical complexities, involvement of a diverse range of stakeholders, and high vulnerability to external factors such as sanctions, economic fluctuations, environmental challenges, changing regulations, and geopolitical developments, this project provides an ideal context for a comprehensive analysis of external risks. Furthermore, the project’s implementation coincided with key economic and political changes in the country, offering a timely and realistic setting to assess the impact of these risks on the project timelines. Since the executing company (IOPTC) is responsible for numerous similar projects nationwide, the findings from this study are applicable to other comparable projects as well. Consequently, this case study not only enhances the understanding of external risks in large-scale oil projects in Iran but also offers valuable insights for other developing economies facing similarly high-risk environments.

3.2 Methodological Steps

This study used a detailed and systematic methodology to identify, analyze, prioritize, and assess the interrelationships among external risks impacting the 16-inch Yazd-Naein oil pipeline construction project in Iran. In the first step, 31 external risks were identified using the Risk Breakdown Structure (RBS), through checklists, expert interviews, and analysis of similar past projects. These checklists were developed using expert knowledge and validated through structured interviews to ensure their accuracy and relevance. Next, a qualitative analysis was performed using the probability and impact assessment technique, offering in-depth insights into the nature and significance of the identified risks. At this stage, using interview techniques and holding expert panels, the experts were asked to independently assess the likelihood of occurrence and the degree of impact of each risk on the project timelines using a Likert scale ranging from "very low" to "very high." To complete this analysis, both the probability of occurrence and the impact of each risk were also quantified numerically. For the probability of occurrence, numerical values were assigned as follows: "very low" = 0.1, "low" = 0.3, "medium" = 0.5, "high" = 0.7, and "very high" = 0.9. Similarly, for the impact of each risk on the project timeline, the following numerical values were considered: "very low" = 0.05, "low" = 0.1, "medium" = 0.2, "high" = 0.4, and "very high" = 0.8. Finally, the composite score for each risk was calculated by multiplying the probability score by the impact score. For example, if the probability of occurrence for a risk is "very high" (0.9) and its impact is "high" (0.4), the composite score would be 0.36. All steps were conducted in accordance with the Project Management Body of Knowledge (PMBOK Guide) standards to ensure the research adhered to international guidelines and provided a solid framework for the processes. After quantifying the probability and impact scores, the risks were categorized into three levels of impact: critical risks (impact greater than 20%), significant risks (impact between 8% and 20%), and acceptable risks (impact less than 8%). Out of the 31 identified risks, 22 were classified as critical and significant risks, as presented in Table 1 (Rose, 2013; Sanchez, 2017). The prioritized risks were then analyzed using the ISM methodology, which examined the interrelationships among risks and provided a clear hierarchical structure for their management. The ISM results offered actionable insights to improve risk mitigation strategies in complex projects. In this study, 24 participants, including project managers, supervisors, and experts directly involved in oil pipeline construction projects, were selected to provide insights and expertise. These participants, representing key stakeholders such as employers, consultants, contractors, and suppliers, were purposively chosen based on their extensive experience and specialized knowledge. The questions posed to participants during the interviews included the following topics:

1- What external risks have you encountered or are you familiar with in oil pipeline construction projects?

2- Considering the provided checklist of risks related to oil projects, which external risks are likely to occur in the case study project?

3- Based on the analysis results of similar past projects, which external risks are more likely to happen in the current project?

4- How would you assess the probability of occurrence for each of the identified risks in the case study project?

5- How do you estimate the potential impact of each identified risk on extending the project’s duration?

6- In light of the Interpretive Structural Modeling (ISM) framework, please share your views on the interrelationships among critical and significant risks within the Structural Self-Interaction Matrix (SSIM).

7- What strategies would you suggest for managing and mitigating critical and significant risks?

Table 1. Prioritization of External Risks Affecting Project Timelines

No	Risks	Probability*Effect (Time)
1	The impact of inflation on the project (C1)	0.72
2	The impact of sanctions on the project (C2)	0.72
3	Presence of encroachers (C3)	0.28
4	Rapid changes in the exchange rate (C4)	0.28
5	Intersection with existing lines and obstacles (C5)	0.28
6	Inability to access and trade with foreign suppliers (C6)	0.28
7	Reduced project efficiency due to high and low air temperatures (C7)	0.28
8	Problems and obstacles caused by certain organizations in obtaining the necessary permits (C8)	0.28
9	Damage to lines due to earthquakes (C9)	0.2
10	Low efficiency of executive operations due to rocky terrain (C10)	0.2
11	Delay in land acquisition (C11)	0.2
12	The project site is located within legal easements or restricted zones (C12)	0.2
13	Lack of specialized personnel in the consulting department (C13)	0.2
14	Floods (C14)	0.1
15	Problems in accessing sources of supply for necessary project materials (C15)	0.2
16	Lack of timely and appropriate supply of materials and goods for project implementation (C16)	0.2
17	Problems in registering Iran as the end-user of imported goods and relying on intermediary countries to utilize these goods (C17)	0.2
18	Problems in obtaining export/import licenses from manufacturing/selling countries (C18)	0.2
19	Water accumulation in drilling channels due to rainfall or irrigation of agricultural lands around the channel (C19)	0.14
20	Local threats (C20)	0.1
21	Weakness in using appropriate and accurate tools during the injection and testing of implemented lines (C21)	0.1
22	Preference for domestic manufacturers over foreign ones (C22)	0.1
23	Landslides (C23)	0.06
24	Problems related to water and electricity supply (C24)	0.06
25	Failure to consider weather and seasonal conditions before starting the project (C25)	0.06
26	Failure to fully identify the capabilities of the manufacturers and suppliers of project goods (C26)	0.06
27	Incompatibility of the specifications of the delivered goods with the required specifications (C27)	0.06
28	No access road to enter the site (C28)	0.06
29	Shortage of goods (C29)	0.06
30	Delay in clearing goods (C30)	0.06
31	Delay in loading, transporting and unloading of goods (C31)	0.06

3.3 ISM method

The ISM approach, introduced by Sage in 1977, is a comprehensive method used to understand the relationships between variables in complex systems (Al-Salim and Al-Abrrow, 2024; Verma et al., 2018). This methodology has become a popular tool among researchers for developing structural frameworks and examining interdependencies (Arantes and Ferreira, 2024; Ranjan et al., 2024). ISM facilitates the classification of factors and helps identify the relationships between them. It is particularly effective for analyzing systems in which qualitative variables interact at various levels of significance. This method determines the driving and dependent powers of variables, providing a clear representation of their interrelationships through Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) analysis. MICMAC classifies variables into four categories based on their influence and dependence (Pansare et al., 2023). The following sections outline the steps involved in applying the ISM method (Govindan et al., 2012).

3.3.1 Formation of the Structural Self-Interaction Matrix (SSIM)

The critical and significant risks identified in the study were incorporated into the SSIM. This matrix evaluates the dimensions and indicators of risks in the YOPCPI project by applying four conceptual relationship modes. Respondents were asked to determine the type of bidirectional relationship between the factors listed in the first row and the first column of the table. The data collected were summarized using the ISM methodology, resulting in the final SSIM. The structural modelling logic relies on frequency-based methods without considering the specific characteristics of the variables. Each cell's final symbol reflects the consensus reached by the majority of experts. Table 2 presents the interrelationships among the dimensions of risks based on the opinions of 10 experts, each with over 10 years of experience in participating in and contributing to oil pipeline construction projects in Iran. The conceptual relationship symbols used are as follows:

V: Variable *i* directly influences variable *j* (i.e., *i* impacts *j*).
A: Variable *j* directly influences variable *i* (i.e., *j* impacts *i*).
X: Variables *i* and *j* have a mutual influence on each other.
O: No direct relationship exists between variables *i* and *j* (i.e., they are independent).
Table 2 displays the SSIM used in this study.

Table 2. Formation of the Structural Self-Interaction Matrix (SSIM)

J / I	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
C1		V	O	V	O	V	O	O	O	O	O	O	V	O	V	V	V	O	O	O	V	V
C2			O	A	O	A	O	O	O	O	V	O	V	A	V	A	A	O	O	V	V	A
C3				O	X	O	O	X	O	O	V	X	O	V	V	O	O	V	V	V	O	O
C4					O	X	O	O	O	O	V	O	V	V	V	O	O	O	O	V	V	V
C5						O	O	A	O	V	V	X	O	V	V	O	O	V	V	V	O	O
C6							O	O	O	O	O	O	A	V	V	X	X	O	O	O	V	V
C7								A	O	A	A	O	A	V	X	O	O	O	O	A	O	O
C8									O	O	X	X	A	V	V	X	X	O	X	A	O	V
C9										O	V	V	O	V	V	O	O	O	V	O	O	O
C10											A	A	A	V	V	O	O	O	V	O	O	O
C11												V	A	V	V	O	O	O	A	X	O	O
C12													A	V	V	O	O	V	V	X	O	O
C13														V	V	V	V	O	V	V	V	A
C14															V	A	A	O	O	A	O	A
C15																A	A	V	X	X	V	A
C16																	X	O	O	O	V	V
C17																		O	O	O	V	V

C18	A	V	O	O
C19		V	O	O
C20			O	O
C21				A
C22				

3.3.2 Formation of the Initial Reachability Matrix (RM)

The previously developed SSIM is converted into the Initial Reachability Matrix (RM). This transformation involves replacing the four conceptual notations in the SSIM (V, A, X, or O) with binary values (1 or 0) according to the following rules:

If SSIM (i, j) = V, then (i, j) in the RM is 1, and the (j, i) entry is 0.
If SSIM (i, j) = A, then (i, j) in the RM is 0, and the (j, i) entry is 1.
If SSIM (i, j) = X, then both (i, j) and (j, i) entries in the RM are 1.
If SSIM (i, j) = O, then both (i, j) and (j, i) entries in the RM are 0.

The resulting RM provides a binary representation of the relationships identified in the SSIM, forming the basis for further analysis of the interdependencies between variables. This step is essential for systematically structuring and visualizing the driving and dependent factors in the ISM process (Ranjan et al., 2024). For the complete RM, refer to Appendix A.

3.3.3 Formation of the Final Reachability Matrix (RM)

After constructing the initial RM, the final RM is developed by incorporating the transitivity of relationships among variables to ensure consistency. This step guarantees that if a significant relationship exists between (i, j) and (j, k), then a significant relationship also exists between (i, k). The transitivity of conceptual relationships is a fundamental assumption in the ISM method, which states that if variable A influences variable B, and variable B influences variable C, then variable A also influences variable C (Priyadarshini et al., 2022; Dong, 2023). At this stage, all indirect relationships between variables are analyzed, and the final RM is generated. The influence power of each variable represents the total number of variables (including itself) that it impacts. The degree of dependence reflects the total number of variables that influence a given variable. The finalized reachability matrix highlights the driving and dependent factors, facilitating strategic decision-making in risk management. For the complete matrix, refer to Appendix B.

3.3.4 Determining the Levels of Factors

To determine the levels and prioritize the variables, the reachability set (variables influenced by a specific variable) and the prerequisite set (variables influencing a specific variable) are identified for each variable. Subsequently, the common elements between the reachability set and the prerequisite set are determined for each variable. Based on these common elements, the levels of the variables are established. In the initial iteration, variables whose reachability set and common elements are identical are assigned the highest level in the ISM hierarchy. Once these variables are identified, they are removed from the matrix, and a new iteration is conducted with the remaining variables. This process continues until all variables are categorized into their respective levels. In this study, all variables were categorized after seven iterations, as shown in Table 3. Due to space constraints, subsequent iterations are not included in the table. The hierarchical structure provided by ISM offers a clear understanding of the influence and dependency relationships among variables. Variables at the highest level are critical drivers, while those at lower levels are more dependent, providing valuable insights for strategic decision-making in project risk management.

Table 3. Criteria Ranking

Criteria	Output elements	input elements	common elements	level
C1	C1-C2-C4-C6-C7-C8-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-	C1-	7
C2	C2-C6-C7-C8-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C21-	C1-C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C13-C14-C16-C17-C20-C22	C2-C6-C7-C8-C10-C11-C12-C13-C14-C16-C17-C20-	3
C3	C2-C3-C5-C7-C8-C10-C11-C12-C14-C15-C16-C17-C18-C19-C20-C21-C22	C3-C5-C8-C9-C11-C12-C13-C16-C17-C19-C20-	C3-C5-C8-C11-C12-C16-C17-C19-C20-	5
C4	C2-C4-C6-C7-C8-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C4-C6-C13-C16-C17-	C4-C6-C13-C16-C17-	5
C5	C2-C3-C5-C7-C8-C10-C11-C12-C14-C15-C18-C19-C20-C21-	C3-C5-C8-C9-C11-C12-C13-C16-C17-C19-C20-	C3-C5-C8-C11-C12-C19-C20-	4
C6	C2-C4-C6-C7-C8-C11-C13-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C2-C4-C6-C8-C13-C16-C17-C22	C2-C4-C6-C8-C13-C16-C17-C22	4
C7	C2-C7-C14-C15-C18-C19-C20-C21-	C1-C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C22	C2-C7-C14-C15-C18-C19-C20-	2
C8	C2-C3-C5-C6-C7-C8-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C2-C3-C4-C5-C6-C8-C9-C10-C11-C12-C13-C15-C16-C17-C18-C19-C20-C22	C2-C3-C5-C6-C8-C10-C11-C12-C13-C15-C16-C17-C18-C19-C20-C22	3
C9	C2-C3-C5-C7-C8-C9-C10-C11-C12-C14-C15-C18-C19-C20-C21-	C9-	C9-	6
C10	C2-C7-C8-C10-C11-C14-C15-C18-C19-C20-C21-	C1-C2-C3-C4-C5-C8-C9-C10-C11-C12-C13-C19-C20-C22	C2-C8-C10-C11-C19-C20-	3
C11	C2-C3-C5-C7-C8-C10-C11-C12-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C2-C3-C4-C5-C6-C8-C9-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C22	C2-C3-C5-C8-C10-C11-C12-C14-C15-C16-C17-C18-C19-C20-C22	3
C12	C2-C3-C5-C7-C8-C10-C11-C12-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C2-C3-C4-C5-C8-C9-C11-C12-C13-C15-C16-C17-C18-C19-C20-C22	C2-C3-C5-C8-C11-C12-C15-C16-C17-C18-C19-C20-C22	4
C13	C2-C3-C4-C5-C6-C7-C8-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C2-C4-C6-C8-C13-C14-C16-C17-C22	C2-C4-C6-C8-C13-C14-C16-C17-C22	6
C14	C2-C7-C11-C13-C14-C15-C18-C19-C20-C21-	C1-C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C22	C2-C7-C11-C13-C14-C15-C18-C19-C20-	2
C15	C7-C8-C11-C12-C14-C15-C18-C19-C20-C21-	C1-C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C22	C7-C8-C11-C12-C14-C15-C18-C19-C20-	2
C16	C2-C3-C4-C5-C6-C7-C8-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C2-C3-C4-C6-C8-C11-C12-C13-C16-C17-C19-C20-C22	C2-C3-C4-C6-C8-C11-C12-C13-C16-C17-C19-C20-C22	5
C17	C2-C3-C4-C5-C6-C7-C8-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C2-C3-C4-C6-C8-C11-C12-C13-C16-C17-C19-C20-C22	C2-C3-C4-C6-C8-C11-C12-C13-C16-C17-C19-C20-C22	5
C18	C7-C8-C11-C12-C14-C15-C18-C20-	C1-C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C22	C7-C8-C11-C12-C14-C15-C18-C20-	1
C19	C3-C5-C7-C8-C10-C11-C12-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C13-C14-C15-C16-C17-C19-C20-C22	C3-C5-C7-C8-C10-C11-C12-C14-C15-C16-C17-C19-C20-C22	2
C20	C2-C3-C5-C7-C8-C10-C11-C12-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C22	C2-C3-C5-C7-C8-C10-C11-C12-C14-C15-C16-C17-C18-C19-C20-C22	2
C21	C21-	C1-C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C13-C14-C15-C16-C17-C19-C20-C21-C22	C21-	1
C22	C2-C6-C7-C8-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19-C20-C21-C22	C1-C3-C4-C6-C8-C11-C12-C13-C16-C17-C19-C20-C22	C6-C8-C11-C12-C13-C16-C17-C19-C20-C22	4

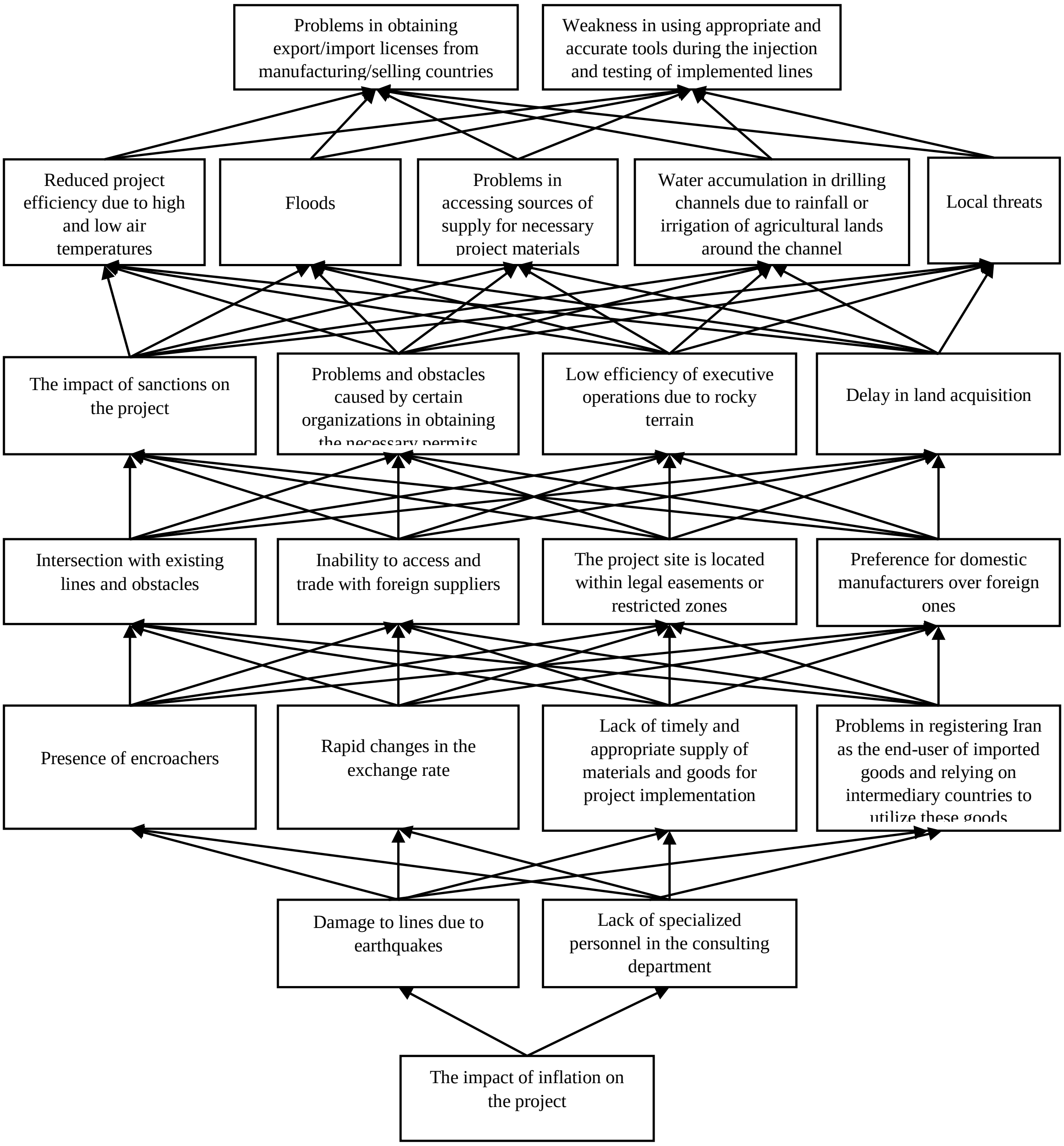

Figure 1. ISM Interaction Network

3.3.5 ISM Interaction Network

At this stage, the final ISM model is developed based on the determined levels and the finalized RM. The model presented in this study consists of seven hierarchical levels, as depicted in Figure 1. The ISM graph illustrates the interdependencies and influence relationships among indicators across different levels. This hierarchical representation provides valuable insights into the critical drivers and dependent factors, facilitating more informed decision-making in complex systems. Figure 1 provides a visual representation of the ISM interaction network, demonstrating the flow of influence from higher-level indicators to lower-level ones. This graphical representation enables stakeholders to easily identify the most influential factors and their downstream effects (Ranjan et al., 2024).

3.3.6 MICMAC Analysis

At this stage, the cross-impact of variables, considering their influence on other variables, is determined using matrix analysis. Based on this analysis, all risks are classified into one of four clusters within the variable impact matrix: autonomous, dependent, linkage, and independent (Li et al., 2022). This categorization is achieved by evaluating each factor's driving power and level of dependency. The first type refers to independent factors with high driving power and low dependency, meaning these risk factors are highly influential in the system and are minimally affected by other risks (Dong, 2023). Linkage risk factors possess both high dependency and driving power, indicating that they are unstable and can influence as much as they are influenced by other risks in the system. Dependent risk factors have high dependency and low driving power, meaning their occurrence heavily relies on other factors. Finally, the autonomous quadrant represents risk factors with low driving power and low dependency, indicating they are relatively disconnected from the system (Priyadarshini et al., 2022). The research model, in terms of driving power and degree of dependence, is shown in Figure 2. The driving power of each variable is determined by summing the values in each row of Table 3, while the degree of dependence is calculated by summing the values in each column of the same table.

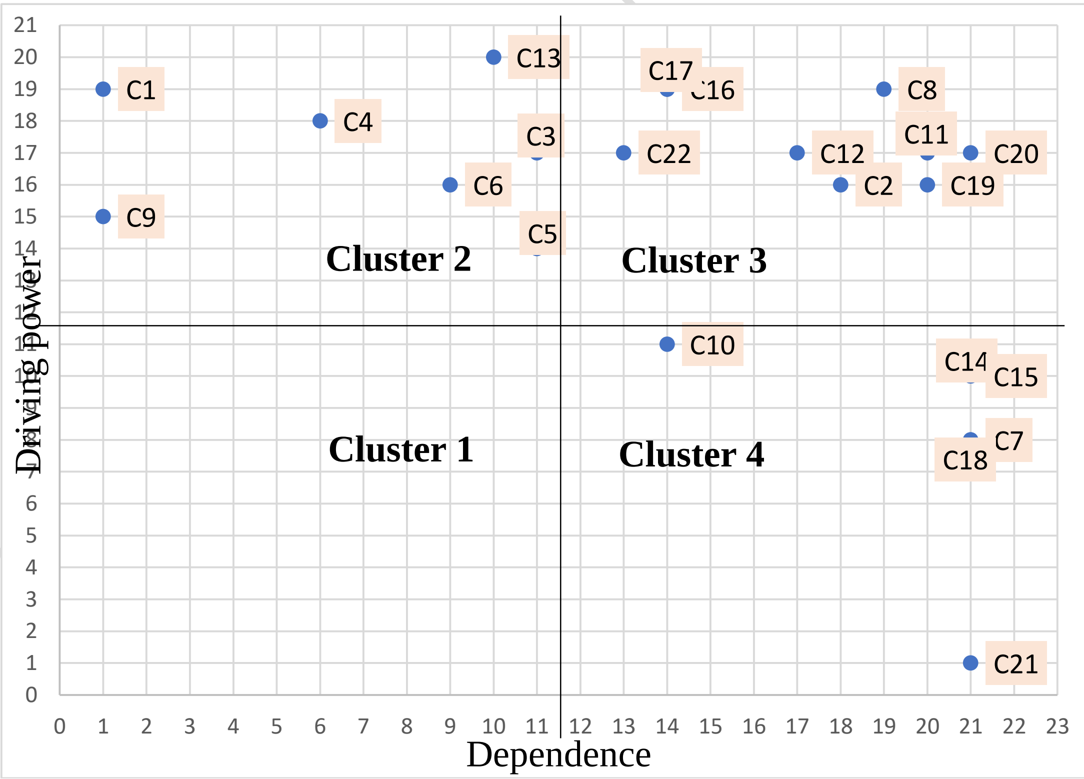

Figure 2. Driving power - degree of dependence matrix

4. Discussion

Oil and gas projects, particularly the construction of oil pipelines, represent a significant portion of Iran's national investment and play a crucial role in driving economic development.

These projects are inherently complex, operate under unique conditions, and face challenges related to time, cost, and quality, all of which highlight their importance. As the third-largest holder of global oil reserves, Iran must prioritize effective risk management strategies in this sector. Although numerous studies have explored risk management in oil pipeline projects, the interplay between managerial challenges and external risks in Iran remains insufficiently explored. This study addresses this critical research gap by focusing on external risks that uniquely affect project timelines. It provides a comprehensive framework for identifying, analyzing, prioritizing, and assessing the relationships among external risks affecting timelines in oil pipeline construction projects in Iran. While specifically designed for the Yazd-Naein Oil Pipeline Construction Project, the framework is adaptable to similar projects in the oil industry.

The ISM analysis revealed a hierarchical risk structure, with inflation having the greatest influence. Positioned at the lowest level, inflation was independent of other risks but exerted a direct impact on risks like earthquake damage to pipelines and a shortage of specialized personnel in the consulting department, which were categorized at the sixth level. These risks propagated upward, affecting higher levels and ultimately influencing the highest-level risks. This hierarchical insight underscores the necessity of prioritizing high-impact, low-dependency risks to ensure effective risk management.

The MICMAC analysis categorized risks into four groups, providing valuable insights into their influence and interdependencies. Risks such as the impact of inflation on the project, the presence of encroachers, rapid changes in the exchange rate, intersections with existing lines and obstacles, inability to access and trade with foreign suppliers, pipeline damage due to earthquakes, and a shortage of specialized personnel in the consulting department exhibited high driving power and low dependency. These risks exert the greatest influence on other risks and should be prioritized in project risk management.

In contrast, risks such as reduced project efficiency due to extreme air temperatures, low efficiency of executive operations due to rocky terrain, floods, difficulties in accessing supply sources for necessary project materials, issues in obtaining export/import licenses from manufacturing or selling countries, and weaknesses in using appropriate tools during the injection and testing of implemented lines demonstrated high dependency on other risks. These risks are considered dependent and are primarily triggered by other risks, with limited potential to initiate new risks themselves.

Additionally, risks such as the impact of sanctions on the project, obstacles caused by certain organizations in obtaining necessary permits, delays in land acquisition, the project site being within legal easements or restricted zones, lack of timely and appropriate supply of materials, problems in registering Iran as the end-user of imported goods and reliance on intermediary countries, Water accumulation in drilling channels due to rainfall or irrigation of agricultural lands around the channel, local threats, and preference for domestic manufacturers over foreign ones not only affect other risks but are also influenced by them. If changes occur within these dynamic risks, they can significantly affect the overall project system.

Based on the categorization of risks according to their driving power and dependency levels, risks response strategies were developed through semi-structured interviews with project managers, supervisors, and experts. These strategies are detailed in Table 4.

Table 4. Risk Response Strategies

Strategies for High Driving Power and Low Dependency Risks	
Risk	**Strategies**
The impact of inflation on the project	Allocate sufficient advance payment to the contractor for purchasing essential project items and equipment at the start.
presence of encroachers	Before execution, gather accurate information about encroachers and resolve disputes through negotiation and compensation.
Rapid changes in the exchange rate	Contracts should be in foreign currency.
Intersection with existing lines and obstacles	Use advanced surveying and field visits to identify routes with minimal intersections.
Inability to access and trade with foreign suppliers	Utilize local suppliers with support and incentives.
Damage to lines due to earthquakes	Use seismic-resistant infrastructure and real-time monitoring systems.
Lack of specialized personnel in the consulting department	The project consulting department should enhance human resources by organizing specialized training courses with reputable universities and institutions.
Strategies for High Dependency and Low Driving Power Risks	
Risk	**Strategies**
Reduced project efficiency due to high and low air temperatures	Accurate project scheduling based on weather forecasts, and use of temperature-resistant equipment.
Low efficiency of executive operations due to rocky terrain	Use of specialized equipment, and geological analysis.
Floods	Implementation of effective drainage systems and weather forecasts for proactive flood management.
Problems in accessing sources of supply for necessary project materials	Establish centralized warehouses and long-term agreements with reliable suppliers.
Problems in obtaining export/import licenses from manufacturing/selling countries	Collaboration with government agencies to facilitate the licensing process, and diversification of supply sources to reduce dependency.
Weakness in using appropriate and accurate tools during the injection and testing of implemented lines	Conducting specialized training courses, using precise and advanced equipment, and establishing documented protocols for testing and injection
Strategies for High Dependency and High Driving Power Risks	
Risk	**Strategies**
The impact of sanctions on the project	Strengthen the domestic sector and utilize contractors capable of executing projects under sanctions.
Problems and obstacles caused by certain organizations in obtaining the necessary permits	Establish task forces before project execution to facilitate permitting and ensure clear communication with authorities.
Delay in land acquisition	Before execution, negotiate with landowners, establish transparent frameworks for land acquisition and compensation, and obtain necessary agreements.
The project site is located within legal easements or restricted zones	Obtain necessary agreements from relevant authorities before project execution to carry out the project in restricted areas with legal easements.
Lack of timely and appropriate supply of materials and goods for project implementation	Strengthen inventory management systems in the employer and contractor sectors and provide support for local manufacturing.
Problems in registering Iran as the end-user of imported goods and relying on intermediary countries to utilize these goods	Establish direct relations with foreign suppliers and develop domestic customs and trade infrastructure.
Water accumulation in drilling channels due to rainfall or irrigation of agricultural lands around the channel	schedule drilling based on weather forecasts, and use physical barriers in sensitive areas.
Local threats	Build trust with local communities by investing in social projects and improving site security.
Preference for domestic manufacturers over foreign ones	Requiring domestic manufacturers to improve the quality of their products according to global standards, and using foreign manufacturers for critical sections.

According to expert opinions, among the identified risk response strategies, those in the first group (high driving power and low dependence) are considered the most effective approach because these risks act as the system's driving engines. Controlling and mitigating these risks not only directly reduces their own probability and impact scores but also indirectly decreases the probability and impact scores of dependent downstream risks within the structure. For example, the strategy of allocating sufficient advance payments to contractors for purchasing essential items and equipment at the beginning of the project to mitigate the risk of inflation impact can, in addition to reducing the risk of cost increases, also minimize delays in equipment procurement and risks related to external supply. Similarly, the strategy of entering into foreign currency contracts to counteract the risk of rapid exchange rate fluctuations directly controls financial volatility and reduces dependence on secondary cost-related risks. The use of earthquake-resistant infrastructure lowers the likelihood of damage and consequently limits the related consequences such as repairs, delays, and reconstruction costs. Conversely, strategies related to risks with low driving power and high dependence are more reactive in nature and only reduce the specific risk itself, meaning they do not have a cascading effect within the structure. Examples include project scheduling based on weather forecasts or long-term agreements with reliable suppliers, which have limited and localized effects. Therefore, the best approach to managing project risks is to prioritize the implementation of first-group strategies to stabilize the risk dependency network and maximize the reduction in both the probability and impact of risks.

5. Conclusion

This study presents an innovative framework for managing external risks affecting timelines in oil pipeline construction projects and addresses a significant gap in the research literature. By utilizing the ISM method, a hierarchical structure of risks was analyzed, offering a clearer understanding of their complex interactions. The findings indicate that risks such as inflation and sanctions, both of which have high driving power, have the greatest impact on project timelines and overall success. However, inflation is identified as an independent risk with minimal dependency on other risks, while sanctions, due to their higher dependency on other risks, require more careful management. Proactively managing these risks can prevent cascading delays and additional costs.

The proposed framework provides project managers with actionable insights for identifying vulnerabilities and implementing effective risk mitigation strategies. It underscores the importance of meticulous monitoring and management, particularly for risks such as the impact of inflation on the project, the presence of encroachers, rapid changes in the exchange rate, intersection with existing lines and obstacles, inability to access and trade with foreign suppliers, damage to pipelines due to earthquakes, and a shortage of specialized personnel in the consulting department, which could compromise project stability.

One of the most compelling aspects of this study is the unanimous agreement among experts on the practicality of the proposed framework. The experts involved in the project confirmed that this model would significantly enhance the efficiency of similar projects, particularly in terms of time and resource management. This empirical validation underscores the robustness and reliability of the framework.

Furthermore, applying the ISM method to Iran’s infrastructure projects could mark a turning point in the management of large-scale initiatives. This method not only aids in identifying key risks but also provides profound insights into their interdependencies, enabling project managers to make more informed and effective decisions. Implementing this framework will help reduce uncertainties, improve project success rates, and foster the sustainable development of Iran’s oil and gas sector. By offering a comprehensive understanding of external risks and their interconnections, this study equips managers with the necessary tools to navigate challenges and optimize project performance.

Recommendations for Future Research:

Expanding the Model to Other Industries - Applying the proposed framework to other infrastructure sectors, such as petrochemicals, power plants, and heavy industries, could reveal both shared and industry-specific risks, thus enhancing its applicability and value.

Exploring the Role of Emerging Technologies in Risk Management - Investigating how advanced technologies such as blockchain, IoT, and artificial intelligence can integrate with the ISM method may improve the precision of risk analysis and offer innovative solutions for risk mitigation.

Analyzing the Impact of Economic Policies and Sanctions - Given the critical role of sanctions and economic fluctuations in Iran's oil and gas projects, future research could examine the interplay between economic policies and external risks to develop more adaptive and robust risk management strategies.

International Comparative Studies: Comparing the risks and risk management approaches of oil pipeline projects in other oil-rich countries, such as Saudi Arabia, Iraq, and Russia, could provide valuable insights for refining Iran's strategies and practices.

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Appendix:

Appendix A: Initial Reachability Matrix (RM)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
C1	0	1	0	1	0	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	1	1
C2	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1	0
C3	0	0	0	0	1	0	0	1	0	0	1	1	0	1	1	0	0	1	1	1	0	0
C4	0	1	0	0	0	1	0	0	0	0	1	0	1	1	1	0	0	0	0	1	1	1
C5	0	0	1	0	0	0	0	0	0	1	1	1	0	1	1	0	0	1	1	1	0	0
C6	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1
C7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
C8	0	0	1	0	1	0	1	0	0	0	1	1	0	1	1	1	1	0	1	0	0	1
C9	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	1	0	0	0
C10	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0
C11	0	0	0	0	0	0	1	1	0	1	0	1	0	1	1	0	0	0	0	1	0	0
C12	0	0	1	0	1	0	0	1	0	1	0	0	0	1	1	0	0	1	1	1	0	0
C13	0	0	0	0	0	1	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	0
C14	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
C15	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
C16	0	1	0	0	0	1	0	1	0	0	0	0	0	1	1	0	1	0	0	0	1	1
C17	0	1	0	0	0	1	0	1	0	0	0	0	0	1	1	1	0	0	0	0	1	1
C18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
C19	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	0	1	0	0
C20	0	0	0	0	0	0	1	1	0	0	1	1	0	1	1	0	0	0	0	0	0	0
C21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1	0

Appendix B: Final Reachability Matrix (RM)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	Driving power
C1	1	1	0	1	0	1	*	*	0	*	*	*	1	*	1	1	1	*	*	*	1	1	19
C2	0	1	0	0	0	*	*	*	0	*	1	*	1	*	1	*	*	*	*	1	1	0	16
C3	0	*	1	0	1	0	*	1	0	*	1	1	0	1	1	*	*	1	1	1	*	*	17
C4	0	1	0	1	0	1	*	*	0	*	1	*	1	1	1	*	*	*	*	1	1	1	18
C5	0	*	1	0	1	0	*	*	0	1	1	1	0	1	1	0	0	1	1	1	*	0	14
C6	0	1	0	1	0	1	*	*	0	0	*	0	*	1	1	1	1	*	*	*	1	1	16
C7	0	*	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	*	*	*	*	0	8
C8	0	*	1	0	1	*	1	1	0	*	1	1	*	1	1	1	1	*	1	*	*	1	19
C9	0	*	*	0	*	0	*	*	1	*	1	1	0	1	1	0	0	*	1	*	*	0	15
C10	0	*	0	0	0	0	1	*	0	1	*	0	0	1	1	0	0	*	1	*	*	0	11
C11	0	*	*	0	*	0	1	1	0	1	1	1	0	1	1	*	*	*	*	1	*	*	17
C12	0	*	1	0	1	0	*	1	0	1	*	1	0	1	1	*	*	1	1	1	*	*	17
C13	0	*	*	*	*	1	1	1	0	1	1	1	1	1	1	1	1	*	1	1	1	*	20
C14	0	1	0	0	0	0	*	0	0	0	*	0	*	1	1	0	0	*	*	*	*	0	10
C15	0	0	0	0	0	0	1	*	0	0	*	*	0	*	1	0	0	1	1	1	1	0	10
C16	0	1	*	*	*	1	*	1	0	0	*	*	*	1	1	1	1	*	*	*	1	1	19
C17	0	1	*	*	*	1	*	1	0	0	*	*	*	1	1	1	1	*	*	*	1	1	19
C18	0	0	0	0	0	0	*	*	0	0	*	*	0	*	*	0	0	1	0	1	0	0	8
C19	0	0	*	0	*	0	*	1	0	*	1	*	0	*	1	*	*	1	1	1	*	*	16
C20	0	*	*	0	*	0	1	1	0	*	1	1	0	1	1	*	*	*	*	1	*	*	17
C21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
C22	0	1	0	0	0	*	*	*	0	*	*	*	1	1	1	*	*	*	*	*	1	1	17
Dependence	1	1	1	6	1	9	2	1	1	1	2	1	1	2	2	1	1	2	2	2	2	1	