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REGIONAL DEVELOPMENT THROUGH ENERGY INFRASTRUCTURE: A COMPARISON AND OPTIMIZATION OF IRAN-PAKISTAN-INDIA (IPI) & TURKMENISTAN-AFGHANISTAN-PAKISTAN-INDIA (TAPI) GAS PIPELINES

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Research Article

Abstract: *Pakistan is working on two pipeline projects, namely, Iran-Pakistan-India (IPI) and Turkmenistan-Afghanistan-Pakistan-India (TAPI) gas pipelines, to meet its energy supply-demand gap. This study's aims to compare these two projects and identify the most suitable option for Pakistan. Furthermore, as the TAPI project is progressing faster than the IPI project, this study also aims to identify the critical activities associated with TAPI projects. Finally, a model is proposed to optimize the material and transportation costs related to the TAPI project. The study's contribution by using fuzzy set theory-based multi-criteria decision-making (Fuzzy MCDM) to compare two projects along with usage of the Fuzzy Critical Path Method (FCPM) for the identification of critical activities associated with the TAPI project. Finally, the Genetic Algorithm is applied to optimize the material and transportation costs of the TAPI project. The results show that IPI has advantages over TAPI in terms of power generation, transportation cost, transits fee, and gas prices. The critical path analysis of the TAPI gas pipeline shows that it will take approximately 75 to 330.5 weeks to complete. The study is useful for the managers who have to work in these projects, the policymakers considering these projects at various levels, and the researcher having an interest in applying Fuzzy set theory with MCDM, CPM, and in the context of the energy infrastructure.*

Key words: *Optimization models, Fuzzy TOPSIS, Fuzzy CPM, Genetic Algorithm, MCDM, TAPI, IPI*

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1. Introduction

Pakistan is confronted with increasing energy demand and the energy demand-supply gap (Ali, et al., 2020a). Pakistan's energy mix is dominated by thermal sources, mainly imported from Middle East countries (MoF, 2020). Although Pakistan has been producing oil and gas locally, it is insufficient to meet its energy demand (MoF, 2020). Pakistan's geographic closer locations to oil-rich middle-eastern countries and its land connection with Iran and natural gas-rich Central Asian States (via Afghanistan) give it a geographic advantage. Historically, Pakistan has heavily relied on oil imports from the Kingdom of Saudi Arabia (KSA) and the United Arab Emirates while ignoring the neighbour Iran mainly due to economic sanctions on Iran.

To meet its growing energy demand, Pakistan has been exploring multiple options. These options include an increase in local exploration of energy sources and identifying and connecting to importing energy resources from other countries. In this regard, there has been a discussion on projects like the Iran-Pakistan-India (IPI) pipeline that was planned to connect these three countries for gas supply from Iran. However, the IPI project could not be implemented according to the expectations and plans due to international sanctions on Iran and pressure from the United States and KSA. The alternative to the IPI pipeline project that is proposed, debated, and supported by the stakeholders is Turkmenistan-Afghanistan-Pakistan-India (TAPI) gas pipeline. TAPI has support from both the USA and the KSA. However, there are concerns over the safety and security of the TAPI pipeline, especially across Afghanistan. Also, there are issues with funding for the project. However, currently, the IPI pipeline project is not progressing significantly compared to the TAPI pipeline project.

This study has two main objectives. First, the study does a feasibility comparison of IPI and TAPI gas pipeline projects for Pakistan. We consider several factors such as capacity, length, costs and other associated benefits and costs of these two projects to undertake its feasibility. Secondly, given the fast progress on the TAPI project, the study also identifies the critical activities being involved in the TAPI pipeline project and suggests cost optimization that may help implement the TAPI pipeline project. Finally, the study also proposes a model to optimize the material and transportation costs related to the TAPI project. To the best of our knowledge, no such analysis is undertaken for these two projects. The major contribution of this study is the first of its type comparison of the IPI and TAPI pipelines project and the application of fuzzy set theory based multi-criteria decision method (MCDM) TOPSIS (Technique for Order Preference Similarity to Ideal Solution) and Critical Path method (FCPM) along with the application of a genetic algorithm for the optimization of TAPI project. These techniques are not employed in such a context in earlier literature. Thus, the study contributes also in terms of the application of advanced decision-making techniques in feasibility studies.

The rest of the study is organized as follows: Section 2 is a Literature review. Section 3 consists of an overview of the IPI and TAPI pipeline projects and their comparison. Furthermore, Section 4 presents the fuzzy TOPSIS, Fuzzy CPM, and Genetic Algorithm and the various steps associated with each method. This section also describes the data and the sources used in this study. Section 5 presents the results of the study. Finally, section 6 concludes the study.

2 Literature Review

The literature review section is divided into subsections. The first subsection discusses studies associated with IPI and TAPI projects. The second subsection discusses the studies on the methodological aspects of these studies

2.1 The literature on IPI and TAPI projects

There are various aspects of scholarly studies focusing on IPI and TAPI projects. For instance, several studies discuss feasibility aspects (economic or political) of TAPI or IPI projects. Some researchers discuss both projects together while considering a single-country perspective. The feasibility studies covering either TAPI and IPI or even both are undertaken from different project partner countries. For instance, Pandian (2015) studied the Indian perspective for the IPI project. Similarly, Hudaa & Ali (2017) covers the TAPI project from Pakistan's perspective. Below we discussed scholarly studies that are explored these two projects from different member countries' perspectives.

The study of Pandian (2005) does discuss the IPI project from the Indian perspective. The research performed a qualitative cost-benefit analysis and argued that the IPI project could work as a confidence-building between India and Pakistan to create an energy partnership between the two countries and open up more possibilities for commercial businesses. Sahir & Qureshi (2007) examined the Pakistani perspective on the region's energy security and its role as an energy corridor. The study also briefly describes Pakistan's importance for pipeline projects (such as IPI and TAPI) that could meet India and China's energy needs along with benefits to Pakistan. Similarly, Abbas (2015) describes a brief history of IPI and TAPI projects in Pakistan's energy needs. Also, Pradhan (2020) described in detail the TAPI project and its importance for India. The study also detailed the reasons for delays in the project and the lack of interest of international firms to finance the TAPI project.

The IPI project is vital for India because it will provide a four-time cheaper gas than other sources, even after paying the transit fee to Pakistan (Pradhan, 2020). Furthermore, the project will bring earnings for Pakistan and improve energy security in both India and Pakistan. The project could ensure a path for energy and trade connectivity across the South-Asia. However, as per Pradhan (2020), Pakistan and India disagree on the transits fee. Furthermore, India has concerns over the continuation of supply in case of a rise in political conflict. KSA is not in favour of this project. But, China has shown interest in participating in the IPI project. In this situation, Pakistan can still enjoy transits country status (Pradhan, 2020).

Mahmood et al. (2014) studied to make assessments for Pakistan's energy needs. So the study assesses the energy that Pakistan can obtain from various energy sources and do discuss the energy import options from IPI and TAPI gas pipelines. The study describes these projects' potential to meet Pakistan's future energy needs and consider energy from other possible sources. However, Mahmood et al. (2014) do not undertake direct feasibility studies of these projects or make any comparison. Similarly, Munir et al. (2013) is also not a full feasibility study. However, Munir et al. (2013) referred to the IPI project as viable for Pakistan with a net reduction of import bill by US$2.3 billion annually with generating 4000 MW of electricity. However, the international geopolitical conditions and the Iran economic sanctions were considered a point of concern for this project's success for Pakistan.

It is essential to highlight the geopolitical conditions that strongly influence both these projects in South and Central Asia. There are various aspects of international politics and countries like the USA, China, Russia, Saudi Arabia, and the member countries of the project. There are abundant studies that discuss various aspects of international relations and geopolitics and their impacts on these projects. For instance, Hudaa & Ali (2017) emphasized increasing the number of stakeholders in mega projects (like TAPI) beyond the member countries. They argue that such an approach may bring a better political consensus and earn more significant support and the shifting focus from the projects' security to inclusiveness and cooperation.

Lee (2014) explored the opportunities for diversification of Turkmenistan gas export routes and related risks. The study also highlights the TAPI project from Turkmenistan's perspective, discusses the various international events and China's role, and argues that these events are causing delays in implementing the TAPI project. Anceschi (2017) interestingly called TAPI a virtual pipeline, given its delays and misinformation around the project while no work was started on its implementation. Furthermore, Anceschi (2017) referred to some studies and raised concerns about the overall viability and security concerns particularly that of the 750 lengths planned to be in the Afghanistan region. Similarly, Khan (2012) focused on the IPI pipeline project, the USA sanctions, and its resultant situation and its implementation for Pakistan and other countries involved.

The other aspect of the project is its safety and security. In particular, for the TAPI project as passes through Afghanistan. India has concerns over the project's safety and security, especially if it has not a good relationship with Pakistan. For instance, Pradhan (2020) highlights concerns over the pipeline's protection in Afghanistan and the Pakistan-Afghanistan border region. The study also insisted that the gas supply should be ensured, and a proper mechanism should be placed that must be independent of the Pakistan-India political relations. The study refers to the project as a win-win for all the participating member countries.

The recent delays in these project implementations are also of concern for the partner countries. Sadat (2015) describes five phases for the implementation of TAPI phases. Accordingly, the first few phrases that required signing the framework and agreements, sales, and purchases of gas agreements are already completed. However, other aspects, in particular, the implementation of the project itself is not completed. Sadat (2015) referred to security, scarcity of the required funds, diplomatic relationships of the member countries, and alternative energy sources' availability as significant delays on further progress on the TAPI project. Joshi (2011) studied the economics and politics associated with the TAPI pipeline and refer it to a plan that does not proceed beyond discussion due to Afghanistan and Pakistan's conditions, thus suggesting that India explore alternative options and courses of action for its energy needs.

More recently, Rajpoot & Naeem (2020) did the feasibility of the TAPI project. They emphasise the TAPI project as being more valuable for meeting the energy crisis of Pakistan and India. However, the study has not employed any decision making or advanced techniques instead is based on published literature and media reports. According to, Khetran (2020), for successful implementation of TAPI the bilateral relationship between India, Pakistan, and Afghanistan is important. Rajmil, et al.

(2021) debated the nature of the relationship between China, Iran and Pakistan in form of their common economic corridor. Accordingly, they argue that despite their partnership being built through Belt and Road Initiative investments, but future of such relations mainly depends on the mutual relationship between Pakistan and India. All these developments have implications for the implementations of TAPI and IPI projects.

2.2 Research methods used for studying IPI and TAPI projects

The studies discussed above are mainly based on qualitative techniques. For instance, Khetran (2020) (based on published media reports and scholarly articles), Hudaa & Ali (2017) (interview of policymakers), Pandian (2005) (qualitative cost-benefit analysis), Sahir & Qureshi (2007) (regional geopolitical and energy concerns), Abbas (2015) (energy needs), and Anceschi (2017) (qualitative analysis). Furthermore, these studies are mostly focused on a single project (TAPI or IPI) from a unique country perspective and with a lack of applying formal economic viability or feasibility techniques. Even if some studies discussed both projects, it does not go beyond the deceptive analysis.

The scholarly literature on infrastructure projects does employ several methods for analyzing the economic viability of infrastructure projects. The most popular among these techniques are traditional cost-benefit analysis (e.g., Ali et al., 2020b). Some other popular techniques are Net Present Value (Ali et al, 2021) and Internal Rate of Return (Ali et al 2021). Another interesting application is that of MCDM based cost-benefit analysis (e.g., Bilal, et al. 2021). Since TAPI and IPI are mega projects, going through multiple countries and have a lot of technical complications, therefore using the traditional method of feasibility (such as cost-benefit analysis) may not be useful due to the absences of the finest data details. Therefore, in the absence of such information, multi-criteria-based decision-making (MCDM) techniques become more relevant for analysis.

This study, therefore, has two major objectives. The study aims to compare IPI and TAPI projects based on several factors (capacity, pipeline lengths, project costs, associated benefits and costs). Due to the unavailability of detailed project data, the study uses MCDM based methodology namely, fuzzy TOPSIS (Technique for Order Preference Similarity to Ideal Solution) (Gopal and Panchal, 2021). Furthermore, the study aims to identify the critical activities in the implementation of the TAPI project, as Pakistan is currently implementing this project. For this purpose, the study uses the fuzzy Critical Path method (FCPM). Finally, the study also aimed to optimize the resource usage in the TAPI project, for which the study employed a genetic algorithm. Thus, the study not only does employ advanced decision-making techniques (i.e., fuzzy MCDM) but also apply them in combination with Fuzzy CPM and genetic algorithm. No previous studies (to the best of our knowledge) on the subject projects or in such context has applied such methodology earlier. Thus, the study contributes to the literature not only by providing a new approach to undertake the feasibility studies of similar projects, but also providing a useful policy direction for the decision-makers associated with TAPI and IPI projects.

3 TAPI and IPI: background

The Turkmenistan-Afghanistan-Pakistan-India (TAPI) and Iran-Pakistan-India (IPI) pipelines are important infrastructure projects for Pakistan's future energy needs. These two international energy supply pipeline projects will be the first of their kind in this region. Below we briefly describe these two projects and presents some relevant details about each of them.

3.1 Turkmenistan-Afghanistan-Pakistan- India (TAPI) gas pipeline project

TAPI project will start from gas fields in South Yolotan Turkmenistan (Galkynysh and adjacent gas fields) and link to Quetta (Pakistan) through the Afghanistan areas of Herat, Nimruz, and Kandahar. In Pakistan, it goes through the Dera Ghazi Khan, Multan, and then onward to Fazilka (India) (Hudaa & Ali, 2017). Figure 1 presents the approximate route of the TAPI gas pipeline project. This pipeline is approximately 1680 km long, with 56-inch pipe diameter, and has a capacity to supply about 3.2 (bcfd) per day gas supply that will be shared between Afghanistan (500 mcfd), Pakistan (1325 mcfd), and India (1325 mcfd) (ISGS, 2020). The cost of the project is estimated to be about US$ 7.74 billion (ADB, 2020).

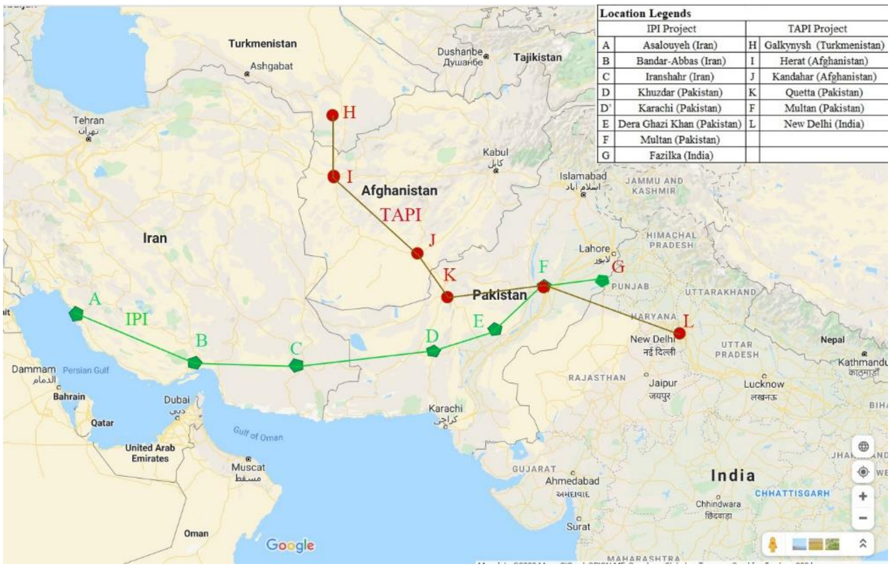

Figure 1. TAPI and IPI project locations (source: Google maps)

TAPI project is essential for Pakistan for several reasons. The gas supply from the project can be used in power generation in Pakistan (Gas through the TAPI pipeline can generate 6,000 megawatts cheaper electricity (Naseem, 2015). This electricity is more than the current electricity generation of the largest Pakistan Tarbela Dam). Although, Pakistan recently ensured LNG from the Central Asian states, however, it will still face the shortages for its need that has been tried to manage with its domestic production (ADB, 2020). Furthermore, the project can ensure a consistent supply of foreign exchange for project life duration in royalty payments from India. Additionally, project construction and operations can lead to further public and private investments and job creations, leading to more economic activities. The intangible benefits could be the improvement in India and Pakistan's relationship, resulting in a peace process in this entire region.

TAPI project would be of equal benefits to India, Afghanistan, and Turkmenistan. Indian economy energy demand is on the rise, and they would be able to get cheaper gas supplies at their doorstep. Afghanistan will earn in royalty from both India and Pakistan, along with creating jobs and employment opportunities that are almost non-existent in their country at the moment. It will be an opportunity for Turkmenistan to expand its energy market and build a more strategic relationship with its customers in the region. According to D'Souza (2017), the TAPI gas pipeline is a game-changer for the countries that are part of it. It will improve their economy and fulfil their energy requirements and eventually become the primary source of enhancing the people's lifestyle in South and Central Asia.

3.2 Iran-Pakistan-India (IPI) gas pipeline project

The Iran-Pakistan-India (IPI) pipeline as a project idea can be traced back to the 1950s. However, the main proposal was placed during 1989, and the three governments agreed upon it during 1999 (Baluch, 2012). The Indian government has withdrawn from the project during 2009. However, the Indian government can still reconsider their decision and later join the project (Haq, 2010). Therefore, we will be considering India as a part of this project while comparing IPI and TAPI in this study.

The IPI project cost is US$ 7.6 billion, with a total capacity of 5.3 billion cubic feet of gas per day, with Pakistan and India share as 2.1 and 3.2 BCFD, respectively. The project was expected to provide about US$ 700 million in transit revenue to Pakistan (MoF, 2007). Pakistan is responsible for constructing a pipeline network on its side, whereas Iran has to build its part. However, currently, due to sanctions on Iran, there is no major progress on the project.

This project is essential for Pakistan because it will provide Pakistan not only, supply of gas from Iran but also will provide much needed foreign exchange in the form of transit fees from India.

3.3 Comparison of TAPI and IPI projects

It is essential to highlight that Pakistan has considered both TAPI and IPI projects due to its energy increasing demand. Due to international geopolitical conditions and Iran's position, Pakistan has been under pressure to prefer the TAPI gas pipeline project over the IPI gas pipeline project. Some studies recommend that the TAPI gas pipeline project is not feasible because of the low gas quality and the unstable situation of Afghanistan (Mazhar & Goraya, 2013).

Furthermore, the TAPI project will be facing significant security challenges due to its passage from Afghanistan, where there are various militant and nationalist troubles, especially in the area of the project (Khetran, 2017). Although Afghanistan will provide full security for the project, India has preferences for it (Khetran, 2017). In the Pakistani region, the TAPI project has no significant threats as it may have in Afghanistan.

Contrary to Mazhar & Goraya (2013), the study from (Kulkarni 2016) refers to the TAPI project as feasible only if its geopolitical and commercial prospects are considered. Similarly, about 99 per cent of the respondents to a survey (in Afghanistan) during 2019 supported this project and viewed it as a role model project for the other national development projects (Saqib, 2019). Finally, the USA is also supporting the TAPI project compared to the IPI project (Hudaa & Ali, 2017) because of sanctions on Iran and its deteriorating relations since the Islamic revolution in Iran back in the 1970s.

The IPI project is facing many challenges. Perhaps the primary problem is that Iran is under United Nations economic sanctions that is a big hurdle for Pakistan and Iran to proceed on this project. Not much progress has been made in more recent years. There have been renegotiations on the same clauses of the project agreement, to make it more workable for the future. There is some comparison provided in Table 1 below for the two projects.

Table 1. Basic statistics of IPI and TAPI projects

Details	IPI	TAPI
Pipeline length (kilometers)	2,775	1,735
Pipeline diameter (inches)	56	56
Pipeline capacity (bcfd*)	5.3	3.2
Project Costs (US$ billions)	7.6	7.74
Global risk factors	Iran sanctions	Nil
Internal risk factor	Political conditions	Safety and Security

* Billion cubic feet per day

Sources: (ADB, 2012; Mahmood, et al., 2014; Hudaa & Ali, 2017; ADB, 2020 and Pradhan, 2020)

4. Research Methodology and Data

This study has multiple objectives. It aims to perform a feasibility comparison of IPI and TAPI projects. Secondly, it identifies the critical activities and optimizes the TAPI pipeline project's material and transportation costs. Therefore, the study uses *fuzzy TOPSIS*, *Fuzzy Critical Path Method (CPM)*, and *Genetic Algorithm*. We divided this section into several subsections and described the applications of each of these methodologies. The last sub-section describes the data used in this study.

4.1. Fuzzy Technique for Order Preference by Similarity to Ideal Solution

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is one of the well-known techniques that are used for Multiple-Criteria Decision Making (MCDM). TOPSIS was introduced by Ching & Kwangsun, (1981) and later modified by Tung, (2000). This technique has been extensively used in various fields, including operations (Ali, et al., 2019), supply chain (Ali, et al., 2020a), and economics (Ali, et al., 2019). The basic idea of TOPSIS is to help in selecting an alternative (among a set of available options) that is closest to the Ideal Positive Solution and farthest from the Ideal Negative Solution. TOPSIS uses linguistic scales for weights.[1] Tung (2000) modified linguistic scales for weight by using fuzzy triangular values, i.e., a fuzzy version of the TOPSIS environment. Fuzzy TOPSIS is also in use in scholarly literature in many applications, for instance, decision making (Khan, et al., 2020), economic development (Bin Hameed, et al., 2020), and supply chain (Ertuğrul & Karakaşoğlu, 2008). Figure 2 shows the typical steps involved for the TOPSIS approach (Minatour, et al., 2015) that are adopted in this study.

Figure 2. Illustrating typical steps in the TOPSIS approach (Minatour, et al., 2015)

The TOPSIS procedure can be described as follows.

Assume that there are N decision-makers with y alternatives among which they have to choose while using y criteria. The various steps for this decision making using Fuzzy TOPSIS will be as follows:

Step 1: In the first step of the Fuzzy TOPSIS procedure, N decision-makers compare all alternatives with a given criterion and then rate each alternative with respect to each criterion.

Step 2: The criteria receiving the most number of selections is taken for criteria weight and fuzzy numbers rating respectively as per set weight criteria. This study adopted the following (Table 2) Linguistic Variable weighting for each criterion.

Table 2. Linguistic variables use for weighting each criterion

Linguistic Variable	Triangular Number
Very High	(1.00,0.25,0.00)
High	(0.75,0.15,0.15)
Moderate	(0.50,0.25,0.25)
Low	(0.25,0.15,0.15)
Very Low	(0.00,0.00,0.25)

Source: (Izadi, et al., 2013)

Step 3: In this step, we will select the appropriate linguistic variable from Table 2 to find the importance weights of different criteria assigned by decision-makers. Weights are assigned to different responses obtained from decision-makers

$$\overline{W_j} = \frac{1}{K}\left[\breve{w}_j{}^1 + \breve{w}_j{}^2 + \ldots + \breve{w}_j{}^k\right] \tag{1}$$

Where $\overline{W_j}$ weight of different criteria assigned by decision-makers.

[1] A linguistic scales for weights extracted from Izadi, et al., (2013) is presented in Table A2 in Appendix.

Step 4: In this step, we will select appropriate linguistic variables from Table 1 to find the importance rating of different alternatives for criteria.

$$\breve{x}_{ij} = \frac{1}{K}\left[\breve{x}_{ij}{}^{1} + \breve{x}_{ij}{}^{2} + \ldots + \breve{x}_{ij}{}^{k}\right] \tag{2}$$

Where $\breve{x}_{ij}{}^{k}$ Is the rating of Kth decision-maker, against alternatives *i* and criteria *j*.

Step 5: Now in this step we will convert linguistic variables evaluation into fuzzy triangular numbers to construct a fuzzy decision matrix as well as determine the fuzzy weight of each criterion. i.e.

$$\tilde{A} = \begin{array}{c c} & \begin{array}{cccc} C_1 & C_2 & \ldots & C_n. \end{array} \\ \begin{array}{c} A_1 \\ \vdots \\ A_m \end{array} & \begin{bmatrix} \breve{x}_{11} & \breve{x}_{12} & \ldots & \breve{x}_{1n} \\ \breve{x}_{21} & \breve{x}_{22} & \ldots & \breve{x}_{2n} \\ \breve{x}_{m1} & \breve{x}_{m2} & \ldots & \breve{x}_{mn} \end{bmatrix} \end{array} \tag{3}$$

Similarly weight:

$$\overline{W_j} = [w_1 \quad w_2 \quad \ldots \quad w_n], \breve{x}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right) \tag{4}$$

Where $\breve{x}_{ij}$ represent a triangular fuzzy number. $A_1, A_2 \ldots\ldots A_n$ Are alternatives and $C_1, C_2, \ldots\ldots C_n$ are criteria.

Step 6: In this step, we will construct a normalized fuzzy decision matrix from above step 5. To avoid lengthy and complex formulation we use a Linear scale so $\bar{R}$ gives normalized values;

$$\bar{R} = \left[\tilde{r}_{ij}\right]_{m\times n} \tag{5}$$

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{C_j^*}, \frac{b_{ij}}{C_j^*}, \frac{c_{ij}}{C_j^*}\right), C_j^* = \max c_{ij} \tag{6}$$

Step 7: In this step, we will construct a weighted normalized fuzzy decision matrix.

$$\dot{U} = \left[\tilde{u}_{ij}\right]_{m\times n} \qquad \text{i = 1, 2, 3.....m} \quad \text{j=1, 2, 3....n} \tag{7}$$

$$\tilde{u}_{ij} = \tilde{r}_{ij} \times W_j \tag{7a}$$

Step 8: This step will determine the fuzzy positive ideal solution (FPIS) as (F^*) as well as fuzzy negative ideal solution (FNIS) as (F^-) mentioned in the below equations.

$$F^* = \tilde{u}_1^*, \tilde{u}_2^*, \ldots\ldots \tilde{u}_n^* \tag{8}$$

$$F^- = \tilde{u}_1^-, \tilde{u}_2^- \ldots\ldots \tilde{u}_n^- \text{ where } \tilde{u}_j^* = (1, 1, 1) \quad \text{and } \tilde{u}_j^- = (0, 0,0), \text{j= (1, 2 ... n)} \tag{8a}$$

Similarly, the distance between two fuzzy numbers can be calculated by vertex method i.e. if X and Y are two fuzzy numbers;

X= (a, b, c) Y= (x, y, z) then

$$\text{D(X, Y)} = \sqrt{\frac{1}{3}\left[(a-x)^2 + (b-y)^2 + (c-z)^2\right]} \tag{9}$$

Step 9: This step will determine the distance from a negative and positive ideal solution.

D steric = $\sum_{j=1}^{n} d(\tilde{u}_{ij}, \tilde{u}_j^*)$ (10)

D negative = $\sum_{j=1}^{n} d(\tilde{u}_{ij}, \tilde{u}_j^-)$ where d shows the distance between two fuzzy numbers

Step 10: This step will determine the closeness factor of each criterion.

$$CC = \frac{\text{D negative}}{\text{D steric} + \text{D negative}} \quad (11)$$

Step 10: Rank the given criteria on basis of the closeness factor. The criteria having more closeness factors will be chosen best in descending order.

4.2. Fuzzy Critical Path Method (FCPM)

The Fuzzy Critical Path Method (FCPM) is based on fuzzy set theory. Fuzzy set theory was introduced by Zadeh, (1996). The fuzzy approach is useful in a decision situation when the past data are not available or relevant (Liberatore & Matthew, 2002). The fuzzy Set theory approach is applied now in every field of technology (Aziz, 2013) and has many applications in various fields, including artificial intelligence, computational intelligence, and data analysis (Mares, 2006).

A project manager may use the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) to manage, monitor, and control project activities. PERT is considered more realistic because it provides three-time durations (most likely, pessimistic and optimistic) of the activities (compared to only one in CPM). These time values are obtained from experts, and the beta distribution is also used (Ramo, 2014). On the other hand, Fuzzy CPM helps plan and control difficult projects like IPI or TAPI. The basic logic behind Fuzzy CPM is the same as simple CPM, but fuzzy triangular numbers or trapezoidal fuzzy numbers are used in Fuzzy CPM. It helps in the identification of critical activities in the Network critical path. Furthermore, it can be employed for gas pipeline construction projects to identify various related activities and critical paths to complete projects without delay. An arithmetic operation can be done on any generalized trapezoidal fuzzy numbers. For example, consider two trapezoidal fuzzy numbers $X = (U_1, U_2, U_3, U_4)$ and $Y = (V_1, V_2, V_3, V_4)$, then the summation and subtraction are (Vahidi & Rezvani, 2013):

$$X + Y = (U_1, U_2, U_3, U_4) + (V_1, V_2, V_3, V_4) = (U_1 + V_1, U_2 + V_2, U_3 + V_3, U_4 + V_4) \quad (12)$$

$$X - Y = (U_1, U_2, U_3, U_4) - (V_1, V_2, V_3, V_4) = (U_1 - V_4, U_2 + V_3, U_3 + V_2, U_4 + V_1) \quad (13)$$

Now, to describe the Fuzzy Critical Path Method (FCPM) technique following notations are used:

N_d:	Nodes in the project network diagram
Act_{ij}:	Activity between the nodes
AFT_{ij}:	Activity fuzzy time of Act_{ij}
FET:	Fuzzy earliest time
FLT:	Fuzzy latest time
FST_{ij}:	Total fuzzy slack time of Act_{ij}
$FCT(P_n)$:	Fuzzy completion time
Num:	Number of activities in our project network diagram

Fuzzy Critical Path Method (CPM) may be applied using the following steps:

Step 1: Consider the fuzzy earliest time (FET_1) value (0, 0, 0, 0).

Step 2: Calculate *Beta value* using the below equation:

$$B = \sum\sum \frac{(Xij-Wij)}{(Xij-Wij)+(Zij-Yij)} \Big/ Num \tag{14}$$

Step 3: Calculate fuzzy earliest time (FET) for each node with the help of the equation given below:

$$FET_j = FET_i + AFT_{ij} \tag{15}$$

Step 4: At the intersection, node compare fuzzy earliest time (FET_{js}) and select the maximum number for fuzzy earliest time (FET_j) for each node.

$$FET_j = max\{FET_i + AFT_{ij}$$

$$FET_j = \max\{(S_a, U_a, V_a, W_a), (S_b, U_b, V_b, W_b)\} \tag{16}$$

Step 4.1: Now, find the values of A_1 and A_2 by using the below equations:

$$A_1 = \min\{S_a, U_a, V_a, W_a, S_b, U_b, V_b, W_b) \tag{17}$$

$$A_2 = \max\{S_a, U_a, V_a, W_a, S_b, U_b, V_b, W_b) \tag{18}$$

Step 4.2: Calculate the values of R (S_a, U_a, V_a, W_a) and R (S_b, U_b, V_b, W_b) with the given below equations:

$$R(S_i, U_i, V_i, W_i,) = \beta[(W_i - A_1/(A_2 - A_1 - V + W) + (1-\beta)[1 - 1 - (A_2 - S_i)/(A_2 - A_1 + V_i - S_i)\} \tag{19}$$

Step 4.3: Select the fuzzy earliest time (FET_j) which is more significant after comparing the results of R(S_i, U_i, V_i, W_i)

Step 5: Find the fuzzy latest time (FLT) for each node by using the equation given below:

$$FLT_j = FET_k + AFT_{jk} \tag{20}$$

Step 6: Intersection nodes Compare the fuzzy latest time (FLT_{js}) and consider the minimum number as FLT_j for each node.

$$FLT_j = min\{FET_k - AFT_{jk}\}$$

$$FLT_j = min\{((S_a, U_a, V_a, W_a), (S_b, U_b, V_b, W_b)\} \tag{21}$$

Consider the sub-steps of *Step 4 as* same for *Step 6*.

Step 7: Calculate fuzzy slack time (FST) for each activity from the given equation below.

$$FST_{ij} = FLT_j - (FET_i + AFT_{ij}) \tag{22}$$

Step 8: From all the paths FCT will be calculated for each one, and the below equation can be used to calculate the FCT for the activities in the possible path node.

$$FCT(P_n) = \sum FST_{ij} \tag{23}$$

Step 9: Minimum number is selected after calculating the FCTs, and the path which has the lowest R-value is taken as a Critical Path.

$$FCT(P_n) = min\{FCT(P_{i)}|i = 1,2,3,4, \ldots . n \tag{24}$$

Activities involved in the Fuzzy Critical Path Method (FCPM):

The TAPI gas pipeline activities were divided into two categories, one for pipeline construction and the other for the gas compression station. In this regard, the two major types of activities are presented below in Table 3 as per Oilscams (2018) and Stephanatos (2014):

Table 3. Activities for Gas Pipelines and gas compression stations

Gas pipelines activities (*Oilscams, 2018)*		Gas compression stations (*Stephanatos, 2014)*	
A	Approval of TAPI gas pipeline	L	Installation of gas compression stations
B	Survey & route design	M	Installation of filters
C	Order of gas pipelines	N	Fitting of suction valves
D	Hiring of workers	O	Fitting of control valves
E	Cleaning & grading of ground for gas pipeline	P	Attachment to the gas pipeline.
F	Trenching of the ground		
G	Stringing & bending of gas pipeline		
H	Welding		
I	Non-destructive & hydrostatic testing		
J	Commissioning		
K	Restoration		

4.3. Genetic Algorithm

Genetic Algorithm (G.A.) is widely used in operations research (and also in computer sciences) for optimization related problems. The main idea behind (G.A.) is based on the theory of the Evolution of Darwin (Mitchell, 1996). The process by its nature is imperative in which a candidate solution with its properties is selected from the population, and this candidate can be "mutated" or "altered" to a new solution called generation; this process is continued till the final solution.

We aim to use the G.A. solution for the optimization of the material and transportation costs of the project. It may be noted that the work on the optimization of material and transportation cost has already been performed by many researchers using other techniques like Linear Programming and Time window constraints (Yadav & Kumar, 2017). However, for the construction of the gas pipeline, G.A. can quickly solve problems with vast data. Furthermore, the G.A. approach has been widely applied in optimizing the gas pipelines to optimize the design cost. For instance, Goldberg & Richardson (1987) used the Genetic Algorithm to optimize the working of a steady-state gas pipeline, which had 10 compressor stations and ten pipes. Each compression station consisted of 4 pumps in series (Goldberg & Richardson, 1987). The study's target is to optimize power consumption at specified controlled and allowable pressure (Goldberg & Richardson, 1987). Similarly, Singh & Nain (2012) designed a new model based on a Genetic Algorithm for selecting the pipe sizes. Some other studies based on genetic algorithm includes Goldberg, (1989) and Narváez, (2003).

This study's optimization model uses the non-dominated sorting genetic algorithm to minimize project costs as given by Equation (25).

$$Minimized\ cost = \sum_{m=1}^{n} Cost \qquad (25)$$

The Genetic Algorithm procedure is applied using the following steps.

Step 1: Choose the type of optimization. The optimization can be single-objective optimization or multiple objective optimizations.

Step 2: Input the population size. The population size tells us the number of times it will run the different solutions. Therefore, the greater the population size, the more time the program will take to run.

Step 3: Choose the type of algorithm. Choose the type of Algorithm from Generational, Generational Elitist, and Steady State.

Step 4: Choose the respective crossover. This operator is used to connect individuals to produce new offspring's having characteristics of their parents. These offspring may have a better solution or a worse solution.

Step 5: Choose the selector. Selector plays an essential role in a genetic algorithm, which is how the algorithm will select solutions. There are three types of selectors used: Roulette, Roulette by Rank, and Tournament.

Step 6: Select the mutator. The mutation operator provides new genetic material during optimization. It has three types: Simple, Simple by Gene, and Adaptive Mutation.

Step 7: Defining chromosomes and linking with MS Excel. All decision variables for the problem give us genes in a genetic algorithm. The genes are comprehended together to form new chromosomes.

Step 8: Defining the objectives. One objective must be defined in a single objective and more than one for multiple-objective function.

Step 9: Define the constraints. Constraints are used to penalize variables for going out of ranges.

Step 10: Run the program. The study used a Microsoft excel add-in tool called SolveXL. This tool uses a genetic algorithm to solve complex problems. The optimization and configuration of the tool are done easily by a build-in user-friendly Wizard. Solve is superior to other commercial products and helps in performing single and multiple objective genetic algorithmic solutions. SolveXL utilizes a COM interface to interact with Microsoft Excel. SolveXL is written in the C++ programming language.

4.4. Data Collection

The data for this study was obtained both from primary and secondary sources. We used three questionnaires for getting the preliminary data required for analysis. These questionnaires were containing structured questions with pre-decided close-ended answers (such as multiple choice and rating scales). The data was collected using Google online survey tool. The data were obtained from 15 experts from the field. All the respondents were experts in the oil and gas industry. The respondents were managers and engineers working in the field for a long period. There were ten factors considered (as given in Table 4), and experts were asked to assign weights to each of these criteria using the four options (Very low, low, medium, high, and very high) as per their experience and knowledge. The data were obtained from all experts for both projects on all these ten factors.

Table 4. Factors consider and the weight assigned by experts

Criterion	IPI	TAPI
Capacity (C1) Gas Price (C2) Transit Fee (C3) Capital Cost (C4) Economic Factors (C5) Length of Pipeline (C6) Power Generation (C7) Time of Completion (C8) Geographical Location (C9) International Support (C10)	Very Low Low Medium-High Very High	Very Low Low Medium High Very High

The data collected through this procedure were more feasible, simpler, and time-efficient. This primary data was used in the usage of Fuzzy CPM and Fuzzy TOPSIS. However, there are many limitations, as many assumptions are made while finding out optimized costs and completion times. The exact duration of activities is not always reliable or sometimes even known (Rao & Nowpada, 2012). But given the uncertain situation and absence of enough published information, this approach was considered appropriate.

The secondary data were also used in this study. For instance, the cost of containers for different length pipes was obtained by consulting an expert field Engineer in Schlumberger. The criterion for Fuzzy TOPSIS was selected based on previous literature confirmed by the same field engineer. We took costing data available on the internet and from experts' opinions as the costing reports of both projects are not published. Parameters can be varied to find out total costs like elevation in the setup of pipelines, temperature, and any accident happening while working as it could cause a change in our Fuzzy CPM values. However, given these limitations, we still believe that it is the best approach to compare these two projects in given uncertain circumstances, where these projects have been under discussion for so long, but still, no significant progress has been made on either of them.

5. Results and Discussion

The result section is divided into three sub-section. These sections represent the results of Fuzzy TOPSIS, Fuzzy Critical Path method and the Genetic Algorithm, respectively. It may be noted that discussion on each of these results is also included in each of these specific sections, respectively.

5.1. Results from Fuzzy TOPSIS

The fuzzy TOPSIS method was applied using the expert ratings being obtained through the steps stated in the earlier section. Table 5 presents the final results of the Fuzzy TOPSIS method.[2]

There are several important observations from Table 5. It is clear that the IPI has an advantage over the TAPI in terms of power generation, transportation cost, transits fee, and gas prices. Furthermore, the *closeness coefficients* (determined using Equation (11)) for IPI and TAPI projects are 0.45299 and 0.43973, respectively. This implies that IPI is better than TAPI in the ranking (IPI > TAPI) in the considered study settings. This implies that the IPI project is ranked higher than the TAPI project.

Table 5. Results of Fuzzy TOPSIS

	IPI		TAPI	
	D Steric	D Negative	D Steric	D Negative
Gas Price	0.046	0.057	0.350	0.046
Transit Fee	0.499	0.367	0.310	0.498
Capital Cost	0.035	0.026	0.353	0.035
Economic factor	0.615	0.272	0.367	0.615
Length of Pipeline	0.045	0.033	0.348	0.045
Power Generation	0.629	0.951	0.371	0.630
Time Completion	0.049	0.086	0.349	0.049
Geographical Location	1.131	0.523	0.626	1.129
International Support	0.049	0.068	0.338	0.049
Capacity	0.033	0.075	0.365	0.033
	Sum of Li +	Sum of Li -	Sum of Li +	Sum of Li -
	3.130	2.457	3.777	3.128
CC (%)	43.973%		45.299%	

These findings are consistent with earlier studies such as Hudaa & Ali (2017) and Munir et al. (2013). These findings may not be unexpected given that with lower cost of gas, lesser security and safety concerns, no third country for transit, and higher supplier indicates better economic choices for IPI compared to TAPI. The major hurdle for IPI implementation is the Iran economic sanctions and the international geopolitical conditions.

[2] We do not include the detailed calculation results of this or other methods to keep the article's length to a manageable level. For interested readers, the detailed tables of the calculations can be provided on the request.

5.2. Fuzzy CPM

As stated earlier, there is significant progress going on TAPI compared to the IPI pipeline project. Therefore, this study undertakes the Fuzzy CPM analysis for identifying the critical activities associated with the TAPI pipeline project. In this regard, Table 6 shows various activities involved in the TAPI gas pipeline, predecessor, and fuzzy time for each activity. These time estimations are based on the experts' survey (also known as trapezoidal fuzzy numbers).[3] The Activity on Arrow (AOA) network is presented in Figure 3. The fuzzy activity time is shown in the form of trapezoidal fuzzy numbers, where a represents the minimum value, and d represents the maximum value.

The network diagram for this study is constructed based on the concept of Activity on Arrow. Figure 3 illustrates the AOA network diagram that is built using activities and their predecessors given in Table 6. Each circle represents a node while the alphabets are showing the activities between the nodes. The dotted lines in Figure 3 represent the dummy activities. The fuzzy time for the dummy activities is considered to be zero making the overall connection between the activities logically correct.

Table 7 shows all considered possible paths from the network diagram and calculated the fuzzy completion time using Equation (23). Subsequently, values of R are calculated for each path using Equation (24) and selected. The minimum value obtained was our critical path for the TAPI gas pipeline project.

Also, Table 8 presents the fuzzy earliest time, fuzzy latest time, and fuzzy slack time (FST) for each node, respectively. The result shows the TAPI gas pipeline project's critical path is (1-2-3-5-6-8-10-12-14-15-16-17-18) possible path, and the activities lying on the critical path are (A-B-D-E-F-G-H-I-J-K). This implies that the activities (A-B-D-E-F-G-H-I-J-K) cannot be delayed. Any delay in critical activity will automatically delay the entire TAPI pipeline project. However, other activities such as (L-M-N-O-P) can be delayed, as they do not lie on a critical path.

Project completion time for the TAPI gas pipeline was calculated by adding up the time duration of all activities on the critical path. The results show that the TAPI gas pipeline will take approximately 75 to 330.5 weeks to complete. However, this time is not consistent with a project of similar nature (Malaysian *Peninsula Gas Utilization* that was constructed in 1984 and is 1700 km long) that was completed in 517.43 weeks. The inconsistency in completion times may be because of many reasons, for instance, the improvement in technology during all these years and not considering all factors involved in the construction of the TAPI gas pipeline. Furthermore, the estimated time from *Peninsula Gas Utilization* is not optimized for the construction. The estimated time for the TAPI pipeline project is determined by Fuzzy CPM and is optimized for completion time.

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[3] The network diagram is the graphical representation of the project's activities, and it is constructed based on the activities predecessors. Generally, two types of network diagrams can be built: Activity on Arrow network diagram and Activity on Node network diagram.

Table 6. Activity fuzzy time for each activity of the TAPI gas pipeline

Activity	Predecessor	Activity fuzzy time AFT (in weeks)			
		a	b	c	d
A	-	48	52	63	70
B	A	9	13	15	20
C	B	2	3	4.5	6
D	B	4.5	5	5.5	7
E	B, D	3.5	5	6	8
F	D,E	5	6	9	12
G	C,F	3	7	8	8.5
H	G	5	6	7.5	9
I	G,H	3	4.5	8	10
J	I	1	1.5	2	3
K	J	1	2	2.5	3
L	C	3	5	7	9
M	L	4	6	8	9
N	M	3	4.5	5.5	7
O	N	2	3.5	5	6
P	O	3	5	6.5	9

Table 7. Fuzzy completion time (FCT_{pi}) and R (FCT_{pi}) values for all possible critical paths of the gas pipeline

Possible paths	Fuzzy completion time FCT (Pi)			R-value	
(1-2-3-4-7-9-11-13-18)	-535	-160.5	270.5	652.5	0.516
(1-2-3-5-6-8-10-12-14-15-16-17-18)	-877.5	-318.5	318.5	877.5	0.486
(1-2-3-6-8-10-12-15-16-17-18)	-742.5	-269.5	269.5	742.5	0.488
(1-2-3-4-10-12-14-15-16-17-18)	-728	-257.5	279.5	751.5	0.493
(1-2-3-5-8-10-12-14-15-16-17-18)	-810	-294	294	810	0.487
X_1=min(all possible paths)	-877.5	*Rmin*		0.485955	
X_2=max(all possible paths)	877.5				
Beta risk factor	0.473				
1-*Beta*	0.528				

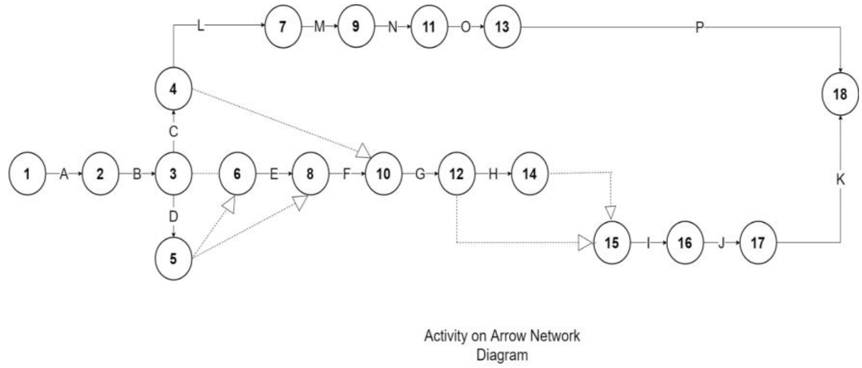

Figure 3 Activity on Arrow Network Diagram of TAPI pipeline project

Table 8. Fuzzy earliest time, fuzzy latest time and fuzzy slack time for each node

Node	Fuzzy earliest time (FET)				Fuzzy latest time (FLT)				Fuzzy slack time (FST)			
	a	b	c	d	a	b	c	d	a	b	c	d
1	0	0	0	0	-68	-25	24.5	67.5	-67.5	-25	25	68
2	48	52	63	70	2.5	38.5	76.5	116	-67.5	-25	25	68
3	57	65	78	90	22.5	53.5	89.5	125	-67.5	-25	25	68
4	59	68	82.5	96	43	70	103	136	-53	-13	35	77
5	61.5	70	83.5	97	29.5	59	94.5	129	-67.5	-25	25	68
6	61.5	70	83.5	97	29.5	59	94.5	129	-67.5	-25	25	68
7	62	73	89.5	105	52	77	108	139	-53	-13	35	77
8	65	75	89.5	105	37.5	65	99.5	133	-67.5	-25	25	68
9	66	79	97.5	114	61	85	114	143	-53	-13	35	77
10	70	81	98.5	117	49.5	74	106	138	-67.5	-25	25	68
11	69	83.5	103	121	68	90.5	118	146	-53	-13	35	77
12	73	88	106.5	125.5	58	82	113	141	-67.5	-25	25	68
13	71	87	108	127	74	95.5	122	148	-53	-13	35	77
14	78	94	114	134.5	67	89.5	119	146	-67.5	-25	25	68
15	78	94	114	134.5	67	89.5	119	146	-67.5	-25	25	68
16	81	98.5	122	144.5	77	97.5	123	149	-67.5	-25	25	68
17	82	100	124	147.5	80	99.5	125	150	-67.5	-25	25	68
18	83	102	126.5	150.5	83	102	127	151	-67.5	-25	25	68

5.3. Genetic Algorithm (G.A.)

This study also optimizes the material and transportation costs involved in the TAPI project using a Genetic Algorithm. In the absence of any number, we will develop a model that, if adopted, the project engineers can optimize the TAPI project's transportation and material costs. We used the Chelpipe firm's data (a Russian Company responsible for supplying pipes to the TAPI gas pipeline project). It is learned that Chelpipe provides customers with different packages giving them discounts as customers buy more containers, as shown in Table 9:

Table 9 Different packages along with their prices for each container

		Quantity Pricing (millions)				
		Length				
Packages	# of Pipeline Containers	1 meter	3 meters	5 meters	7 meters	12 meters
Package A	3	$ 4.50	$ 4.41	$ 4.28	$ 4.19	$ 3.96
Package B	5	$ 7.35	$ 7.20	$ 6.98	$ 6.83	$ 6.45
Package C	12	$ 17.10	$ 16.74	$ 16.20	$ 15.84	$ 14.94
Package D	15	$ 20.25	$ 19.80	$ 19.13	$ 18.68	$ 17.55
Package E	20	$ 24.00	$ 23.40	$ 22.50	$ 21.90	$ 20.40

The diameter of all the pipes is 1.42 meters. The cost values are taken by consulting experts in the oil and gas sectors. The first column in Table 9 shows different Packages, while the second column indicates the number of Containers in that Package. The remaining columns show the price of one meter, 3 meters, 5 meters, 7 meters, and 12 meters containers. For example, by analysis of *Package A* consisting of 3 Pipeline containers, a 1-meter pipe container costs \$4.50 million, 3 meters pipe container costs \$4.41 million, and a 5 meters pipe container costs \$ 4.19 million, and 12 meters pipeline containers cost $ 3.69 million. The difference in prices is due to the weight secured by each container. The cost of 12 meters container is less because most of the container's space will go to waste as the 12 meters pipes are more in length, therefore weighing less and occupying more space. However, a 1-meter pipe takes more space in the container, increasing its weight as more 1-meter pipes can be brought by stacking. This increases the cost of one container of 1-meter pipeline container. The idea is to get the required number of containers at the most minimal cost.

This study optimizes the cost of purchasing 512 containers, which is the value taken *randomly* just to illustrate our model. Table 10 below discusses the number of Packages needed to satisfy the requirement of 512 containers at the cost of $562.43 million. The number of times G.A. will run the program is demonstrated by the population which was configured before running the algorithm. The more the population size, the more time it takes to find an optimized solution.[4] By the analysis of results, it can be determined that eight extra containers are required, which results in more cost. Therefore, if the number of iterations increases, the solution moves toward global value. Like the results achieved, a genetic algorithm can be used to construct models for different parameters like the pipeline material, and pipeline length can be added to further increase accuracy.

Table 10. Optimized cost model by genetic algorithm

Packages	Number of Packages	Total number of Containers for each packages	Per Unit Cost	Total Cost
A	5	15	$4.28	$21.38
B	1	5	$7.35	$7.35
C	0	0	$0.00	$0.00
D	0	0	$0.00	$0.00
E	25	500	$20.40	$510.00

Total cost=$ PKR 538.73 million;
Required Containers= 512;
Total Containers from calculation: 520

The results demonstrated in Table 10 can act like a typical model for minimizing cost if several companies provide different packages, rather than using sophisticated techniques like the heuristic approach and integer programming approach for cost minimization. The model illustrated above can help engineers optimize *the TAPI gas pipeline's material* and *transportation* cost using the above model. Furthermore, the model allows engineers to achieve prices close to the global solution by increasing the number of iterations.

[4] We used a population size of 20; the genetic algorithm results can be presented on request for interested readers.

6. Conclusion

The study is based on the feasibility comparison of the IPI and TAPI projects. As Pakistan's energy demand is on the rise and there is a considerable supply-demand gap, these projects are essential for Pakistan's future energy needs. The study used a fuzzy set-based TOPSIS (a fuzzy MCDM) model to compare the two models and concluded that IPI is more beneficial to Pakistan than TAPI. Furthermore, since more work is ongoing on TAPI rather than on IPI, the study applied the Fuzzy Critical Path Method on the TAPI project to identify the project's critical activities. Finally, the Genetic Algorithm application is applied to a scenario for the TAPI gas pipeline that could be easily extended to a more realistic situation to optimize the material and transportation cost. The approach can help with the reduction of the material and transportation cost significantly.

There are several implications of this study. For instance, Pakistan is focused on TAPI mainly, whereas IPI is the project it must consider based on power generation capacity, transportation cost, transit fee and gas prices comparison of both projects. Therefore, this study recommends that the decision-makers in Pakistan explore the IPI project, especially in the recent geopolitical development. Because China also became a significant buyer from Iran. There are some reports of China showing interest in the IPI project (Pradhan, 2020). Pakistan may work on bringing China on board for this project; this will help meet China's energy demand for the future and make the IPI project economically more beneficial for Pakistan. The participation of China can help to nullify the global pressure against this project. Similarly, the study identifies the approximate time of accomplishing the TAPI gas project as about 75 to 330.5 weeks. These are useful information for policymakers working on the TAPI projects at the national level. Furthermore, the approach of this study can be adapted by the policymakers for comparing such projects globally.

The study is based on MCDM analysis and sample size does not matter much for such studies, however, it would have been better to have a sample from experts across multiple countries except only from Pakistan. This would have enriched the analysis. Some other factors such as consideration of Afghanistan under Taliban (as of 2021) may pose a big challenge for prospects of TAPI. Future studies on these projects must give due consideration to the "government" in Afghanistan as it would greatly influence the successful execution of the TAPI project.

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