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[Enhancing Supply Chain Resilience in Crude Refineries: Strategies for Minimizing Product Loss and Boosting Energy Efficiency]

Muhammad Faisal Zaki Khan[1]
MBA Student
Faculty of Management Sciences, Hamdard University, Karachi
muhammadfaisalzakikhan@gmail.com
Dr. Muhammad Umar[2]
Assistant Professor
Faculty of Management Sciences, Hamdard University, Karachi
Muhammad.umer@hamdard.edu.pk

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ABSTRACT

The current study was focused to increase the supply chain resilience by identifying product losses in crude refinery industry. Modern technological methodologies were implemented to turn combustible gases into valuable resource, enhancing energy generation as well as energy efficiency. Utilizing non-probability sampling, a total of 142 responses from crude refinery professionals were assessed using Smart PLS v 4.0 and multiple regression analysis. The outcomes show that with crude refinery operational performances playing a critical role, technological integration reduces flare losses. Although, the crude oil type did not significantly affect this relation. Equipment implementation such as gas engines as well as fractionators increases the flare gas utilization, generating an energy of 1280 Kw and decreasing consumption of diesel. Apart from these positive results, limitations such as credits delayed letter and huge local taxes were observed. This research concluded that improvising operational performances and technological integration can significantly decrease losses of flare gas and promoting the sustainable practices within oil refinery industry.

Keywords: Supply Chain Resilience; Preventing; Product; Crude Refinery.

Introduction

Natural gas is typically found in the oil and gas industry in its original form as associated petroleum gas (APG), which is largely dissolved in crude oil. APG can be referred to as field gas when it is converted into an energy source. Flare gas, on the other hand, is surplus APG that can be burned off in the field but cannot be processed (Orisaremi et al., 2023). Not only may flare losses cause environmental damage by releasing greenhouse gases into the atmosphere, but they may also have an adverse effect on the economy because flare gas can be used for industrial and energy production (Aigbe et al., 2023; Dinani et al., 2023; Petri et al., 2018). Remedial methods are necessary to mitigate high flare losses since flaring causes a noticeable increase in carbon footprint and a large loss of valuable products. The economic elements selected were fixed capital costs, revenues, and variable operating costs. The environmental component was total greenhouse gas emissions (Dinani et al., 2023). Although many offshore engineers have recently asserted that gas flaring is a dependable safety precaution for risky field operations, such as equipment failures and unanticipated changes in flow line conditions, the truth is that many oil-producing countries take advantage of this argument by continuously flaring above safety limits. The distinction between ordinary flaring and flaring for safety and maintenance needs to be made carefully (Orisaremi et al., 2021). Developing nations are taking time to transition with their inability to speed up the process to revolutionize the flare loss process (Orisaremi et al., 2023). The purpose of this research project is to look at cutting-edge technologies and realistic methods for reducing flare gas emissions. It also looks at how technical developments might be strategically applied to turn flare gasses into useful resources, which might maximize energy output and boost economic efficiency. In-depth analyses of the economic and environmental issues, as well as a realistic solutions appraisal, would encourage sustainable practices in the petroleum sector. The research aims to contribute to the broader goal of supply chain resilience by addressing product loss in crude refineries through innovative and sustainable methods. This study is crucial given the recurring theme of organizational complexity and fragmented governance barriers in designing a more resilient supply chain for the petroleum industry. Addressing these aspects involves introducing additional variables and constraints in the decision-making model. For example, geospatially mapping supply chain systems and their material flows is essential to understanding their relationship with the landscape, particularly in terms of climate exposure (Gebril, 2024). Furthermore, strategic planning and lifecycle assessment are vital for balancing logistical, infrastructural, and operational issues in modern energy projects (Said et al., 2024). By exploring these factors, this research contributes to both the current petroleum sector and future decarbonized energy systems, emphasizing the need for sustainable practices and resilience in supply chain management.

Research Objectives

This research study has the following research objectives:

- Ability of technological advancements to independently impact and reduce flare losses
- Impact of overall refinery operational performance as a mediating factor towards flare losses
- Effect of type of crude being processed as a moderating factor towards flare losses
- Ability of type of crude acting as a moderating factor into determining the operational performance towards affecting flare losses

Research Questions

This research study deals with the following research questions:

- Does technology integration for loss prevention independently contributes to overall refinery operational performance?
- Does operational performance have a mediating impact on flare losses?
- Does technology integration in a refinery contribute towards reduction in flare losses as an independent factor?
- Does the type of crude oil being refined have a moderating impact on a refinery by linking integration of technological advancements to affecting flare losses as being dependent on the aforementioned factors?

Literature Review

Theoretical Foundation

Supply Chain Resilience Theory

Supply chain resilience theory offers a conceptual approach to understanding and improving the ability of supply chains to withstand and recover from disruptions (Ponomarov & Holcomb, 2009). In the context of crude refinery operations, supply chain resilience theory clarifies the need for proactive measures that anticipate and mitigate risks leading to product loss (Ponomarov & Holcomb, 2009; Pettit et al., 2013). Organizations can increase their resilience towards different sorts of interruptions including equipment failures as well as supply chain disruptions by applying principles like inclusivity, elasticity, and cooperation (Ponomarov & Holcomb, 2009; Pettit et al., 2013).

Loss Prevention Theory

This theory seeks to examine the factors that leads to losses in industries related to the processing (Banks et al., 1997). The theory emphasizes on robust procedures that can be implemented while processing. The procedures may include maintenance protocols and technological solutions which may be helpful in reducing the risk of product loss either leaks, spills or any other operational inefficiencies (Banks et al., 1997; Mannan, 2011). By implementing the loss prevention practices with supply chain management can help companies protect from the losses and optimize their operations.

Energy Efficiency and Sustainability Framework

This approach focuses on efficiency of energy and sustainability. It serves as a tool for assessing and enhancing the impact of crude refinery operations (UNIDO, 2016). By employing the required technology and optimizing the use of energy, companies can decrease their carbon footprint and address the environmental issues (UNIDO, 2016; Siddiqui et al., 2018). In addition to that employing sustainability principle in the supply chain strategies may promote long term supply chain resilience by linking the corporate goal with the environmental sustainability (UNIDO, 2016; Siddiqui et al., 2018).

Technological Innovations in Supply Chain Management

Technology advancements i.e. the internet of things, artificial intelligence and blockchain are now helpful in supply chain resilience and preventing the losses in oil refinery operations during the process (Bose et al., 2019). Modern technologies such as IoT enables real time monitoring of the equipment's performance and environmental parameters that can later facilitate in maintenance and risk reduction efforts (Bose et al., 2019; Najjar et al., 2020). Artificial intelligence algorithms can help understanding data sets in detecting the trends and anomalies which help enable maintenance activities and optimization of operational processes (Najjar et al., 2020).

Potentially blockchain technology can improve transparency and traceability across the supply chain hence decreasing the probability of fraudulent activities and safeguard the authenticity of the transactions involved during the process (Bose et al., 2019, Najjar et al., 2020).

Regulatory and Compliance Frameworks

The regulatory and compliance is the backbone of the crude refinery operations practices. Regulatory practices along with environmental protection practices and efficient operations are mandated by the government agencies that can facilitate the safe practices to reduce worker's health issues and also the issues related to the environment. If the compliance to the regulatory bodies is made proper companies can prevent themselves for being heavily fined. This can also bring legal liability to the companies as well as the reputational damage due to the non-compliance (API, 2020; EPA, 2021), hence creating innovative opportunities for reducing supply chain risks and loss prevention. These and other theoretical perspectives should be fully integrated into the research framework as a holistic understanding of the socio-technical problems and potential of providing and maintaining supply chain-resilience to safeguard against loss of life both within and outside of crude refinery operations in the petroleum industry sector. Building on the insight of their combined disciplines, the research should yield recommendations for improving operational efficiency, environmental sustainability and risk management considerations.

In early 21st century, the World Bank estimated that around 110 billion cubic meter of associated gas flares every year globally. This is very huge quantity and enough to meet the combined need of gas of Germany and France, which are two large economies within Europe. This level of wastage is should not be ignored and the gas can be potentially used in an efficient way to meet the energy needs and reduce the environmental impacts. In Africa in the year 2000 around 37 bcm of gas was flared. This situation is really concerning. This amount of gas can generate around 200 terawatt hours of electricity. This can easily meet more than half current need of whole African continent and more than the double need of sub Saharan countries. The flared gas is significantly important for the continent's energy needs. However, this has not been given much attention (Ismail & Umukoro, 2012). Despite efforts to reduce gas flaring, the problem persists. In 2022, annual flue gas production increased to 139 bcm. Although this is a slight 3% decrease from the 2021 global gas flaring volume of 144 bcm, this trend highlights the ongoing challenge of managing and reducing gas flaring on a global scale. The constant and significant volume of gas flared each year points to systemic problems in the oil and gas industry, including inadequate infrastructure, regulatory challenges, and economic incentives to collect and use this gas (World Bank, 2022). The impact of gas flaring on the environment is serious. During the combustion process, large amounts of carbon dioxide (CO_2) and other greenhouse gases are released into the atmosphere, contributing to climate change.

Additionally, gas flaring can produce black carbon (soot), which has adverse health effects and further exacerbates global warming. The release of these pollutants not only affects global atmospheric conditions, but also has local effects, including poor air quality and adverse effects on communities living near burning sites. Economically, natural gas flaring means a significant loss in potential revenue. If the gas is captured and processes it can help generate electricity or directly sold to be used in industrial production. The cost of this loss is very high in the region which energy shortage is an issue along with high prices of energy. For example, in Nigeria electricity is very short, if the gas is saved and utilized it can help eliminate the energy issues in the country which will ultimately help in boosting the economy (Orisaremi et al., 2021). The issue of gas flaring in significant to the economic and environment equally. The continuous flaring of gas globally is a high alert towards implementing such strategies that help prevent flare losses and it is high time to safe the economy and environment from the adverse effects of this gas flaring. Hence, reducing the gas flaring, capture the gas and using it in efficient way is the need of the time. To overcome these challenges government, industry and the international community should collectively take steps for developing and implementing such strategies that promote the sustainable and efficient use of natural resources.

Resilience in the Oil and Gas Supply Chain Locks

Creating resilience in the oil and gas supply chain is essential to manage interruptions and minimize the problem. Interruptions in the emergency lock may cause an increase in the gas level, particularly during operational interruptions when the process is obstructed and the gas is used immediately. To address these desafíos, Elmesmary et al. (2023) remove the importance of integrating flexibility, redundancy and collaboration into the chain. The flexibility of the chain lock refers to the ability to quickly adapt operations in response to changing conditions or unexpected events. In the context of the oil and gas industry, this means that there are adaptable extraction and process timings, or you can quickly change alternate processing routes or processing solutions when the main options are compromised. For example, if a primary gas processing installation occurs temporarily due to maintenance or interruption, keep flexible operating planes to divert the gas to alternative installations or use portable processing units to avoid the need for quenching. In this way, flexibility allows the industry to continue its activities without significant energy loss or significant environmental impact. Redundancy, another critical factor highlighted by Elmesmary et al., (2023) involves having backup systems and resources that can take over when primary systems fail. This may include additional processing capacity, spare parts and alternative logistical routes. Concretely, roundness means that if one part of the supply chain is disrupted, another can intervene to ensure that the gas always remains captured and used with force that is flared. For example, in the Egyptian oil and gas sector, maintaining additional pipeline capacity or supplementary gas treatment uses may use the buffer needed to cope with increases in gas production or temporary shutdowns. primary facilities (Elmesmary et al., 2023).

Collaboration between the different parties involved in the oil and gas supply chain is equally vital. This includes cooperation between extraction companies, processing facilities, logistics providers and regulatory bodies. Effective collaboration can lead to better coordination and communication, ensuring that all parties in the approval chain are aligned in our efforts to minimize impact. Research by Elmesmary et al., (2023) in the context of Egypt states that Oil and gas sector in Egypt provides a useful insight into the impact of flexibility, redundancy and integration on reduction of strategic disruption. The study shows that by increasing the resistance of the gas supply frequency and amount of gas can be reduced even the operations are continued. For example, the study highlights the instances where even the logistic challenges are there, flexible schedules can help maintain gas processing. Policy measures and technological develop also play important role in supporting the supply chain resilience. Government can provide the strict policy that can help adopting the resilience of projects and provide incentives to invest in resilience and infrastructure. The innovation in the field of technology that include data analytics and real time monitoring of the processes can improve the supply chain efficiency to predict and respond to disruptions.

Sustainable Practices and Future Directions

In a comprehensive study, Khezeli et al. (2023) analyzed the importance for the oil sector to face a major transition to sustainable practices, recognizing the importance of the interaction between environmental protection and economic stability. Khezeli et al. (2023) shows the potential to reduce lightning, a widespread problem with major environmental consequences.

This strategic alignment on energy efficiency is consistent with broader societal goals of transitioning to renewable energy sources and providing infrastructure compatible with the integration of emerging energy technologies. In particular, the authors suggest a way forward that goes beyond mitigation efforts, calling on industry to use sustainable alternatives such as hydrogen transport and carbon capture and storage. These programs not only demonstrate a commitment to environmental responsibility, but also open a meaningful path to a more sustainable energy environment. Therefore, the idea of Khezeli et al. (2023) Not only highlighted the need for sustainability in the oil sector, but they also provide a compelling roadmap for its evolution to a more environmentally and economically sustainable future.

Hypotheses Development

One important component that can aid in minimizing and recycling flare losses is technological determinism. Technically and financially, the usage of an integrated gas-gas ejector system in lieu of a compressor is suggested and investigated. The economic analysis's findings showed that the compression method with a parallel three-branch arrangement—each branch having a three-stage-ejector was the best option for recovering flare gas from a typical oil refinery plant (M Obhuo, 2020) . As a result, 90% of the flare gas was recovered during routine refinery operations. This theory proposes that different components of an organization, in this example loss prevention in the form of flare losses, can be separately shaped and influenced by technological improvements (Soroush Eshaghi, 2021). Initially methyl diethanolamine was used as a diluting agent. Entering the second stage, gas gets subjected to a washing flow of amine inside a drum while flowing counter currently. To lower the molar percentage of the inert gases, the flare gas is mixed with other refinery gases. The inert gases, restricted within the flare gas, as they lessen the low heating value of the recovered gas while not actively taking part in the combustion reaction. For this reason, it is crucial to minimize their proportion of the flare gas (Mafel Obhuo, 2020) . The concept design and performance of a liquid ring compressor to handle the flare gas are presented based on experimental data and real-world operating conditions of an Italian refinery. With a discharge pressure of 7 bar, the recovered flare gas flows at an average rate of roughly 400 kg/h. For this aim, a two-stage, 82-kW liquid ring compressor is used; its primary attributes and energy usage are assessed. The annual recovery of flare gas is equivalent to 2900 TOE, or 6600 tons of CDE, or 127, 8 TJ (Gabriele Comodi, 2016). Therefore, we can see how massive of an impact and relationship there is when keeping technological advancements as an independent variable in our efforts to minimize flare losses. Refinery flare losses are positively correlated with technological progress, indicating that improvements lead to a decrease in flare losses.

H1:Technological Integration successfully plays an independent role in reducing Flare Losses.

Before being burned in the DOC, the flare gases are combined with natural gas in the first flared power cycle (FPC1). Expansion takes place partially within a high-pressure turbine, the flare gases are used in the second cycle (FPC2) to reheat the primary heater's exhaust flow (DOC) (Amirhossein Khalili-Garakani, 2021). Indirect combustion of flare gases may outperform FPC2 at low capacities, hence, it is advised for future research. At optimal conditions, FPC1 and FPC2 outperform indirect-combustion power cycles in terms of energy and economy. The theory of resource-based review aids in comprehending how technological integration and internal resources affect operational performance, which in turn affects flare losses. It is feasible to understand how technological integration and other internal resources impact flare losses through operational performance in the framework of resource-based review theory (Ahmad K. Sleiti, 2022) . Data represents that around 40% of gas plant flaring is associated with regular flares, with the remaining gases being flared during gas plant startup to meet gas standard specifications following an emergency or scheduled shutdown.

There has been a lot of research done on reducing typical flares, but none on reducing abnormal flares. Every unit was carefully analyzed, and bottlenecks for a zero flaring starting were identified. Bottlenecks are identified as the temperature of the regenerator bottom and the input gas temperature to the amine gas sweetening unit (Kelvin K. Orisaremi, 2022). It was discovered that the gas temperature had reached 40°C right away after adding sour gas to the H2S absorber. For fifty minutes before to commencement, amine hot circulation was initiated with a 150 cubic meter per hour amine flow rate. Prior to gas feeding, the regenerator's bottom temperature was 129°C. More than 6 times less flare gas was produced overall once zero flaring starter techniques were used and this concluded that a reduction in CO_2 emissions was observed (Nasibeh Hajilary, 2020). There is a negative correlation between the reduction of flare losses and the overall operational performance of the refinery, indicating that lower flare losses are associated with greater operational performance.

H2: Refinery Operational Performance plays a mediating role towards mitigating Flare losses.

A flare gas recovery system performs in relation to its design and operating characteristics by using a liquid ring compressor. The findings show that decreasing the temperature of the amine or increasing the flow rate of the recycling amine can both increase the effectiveness of H2S absorption. Analysis shows it is possible to recover 87% of the available heating value in a flare gas. In an analysis it was calculated that about 2 metric Tons of CO_2 per day was reduced

(Javad Asadi, 2021). The technologies that will enable the realistic, industrial, and large-scale recovery of flare gas from the model feed gas have been selected. Associated gas first enters the sweetening unit in order to remove sour gas from it. The light hydrocarbon-containing NGL unit outlet gas is used as feedstock for the units downstream after the sweet gas is fed into the NGL unit, where the heavy hydrocarbon components are recovered as a condensate stream, or NGL (Khalid Al-Khori, 2021) . A gas sweetening unit processes 279.7 MMSCFD of relevant gas before it enters an NGL unit in the planned flare gas recovery process structure. The heavy hydrocarbon components of the gas are now separated into a condensate stream at this point. Henceforth, due to such an allocation percentage we find that net present value is estimated to be about 1.504 Billion Dollars for the flare gas recovery system. The project's internal rate of return is 42% in these circumstances. The suggested flare gas recovery system in the investigated oilfield can be implemented in an environmentally and financially sustainable manner, according to the results (Ali Mohammadi Dinani, 2023).

H3:Technological Integration can independently impact Flare losses without the impact of any other variable.

Through the application of the Markov technique to system reliability, a novel integrated model was created to evaluate various scenarios that were put forth. The network could supply the energy and water shortages in both cases, and the excess could be sold back to the network. It was demonstrated that the ultimate configuration of flare gas recovery technology is greatly impacted by taking technological reliability into account. The best option was chosen, with a capital cost of $236.94 million, a product sales income of $93.31 million, and a return payback duration of 1.3 years (Mohammad Tahmasebzadehbaie, 2021) . Micro-gas to liquids technology reduced flare gas emissions while increasing diesel composition. High pressure Synthesis gas along with Fischer Tropsch was seen to increase productivity by converting methane gas into a high-end fuel such as FT fuel (Christopher Reddick, 2020) . Feed stocks in gas-to-liquid can be gas generated by gasification of biomass or coal. By production of synthesis gas using flare gas components help produce compounds like methanol oxygenates. In these preliminary stages it was observed that 52% of methane was successfully converted and the main benefit was that utilizing CPOX & FT reactions is a successful was to convert methane into liquid oil products with a final composition of 77% C21+ & 23% C7-C20 (Zhenni Ma, 2016).

Irrespective of the technological advancements we can see how simply utilizing the heated fuel gas network has and impact on flare losses. Refineries can reduce greenhouse gas emissions and save energy by integrating and using discarded and flared gases with the fuel gas network (FGN). The base model now includes the GHG emission notion as a new constraint to limit and regulate flaring.

In order to efficiently mix and feed different fuel sinks, a FGN gathers diverse waste gases, flare gases, and fuel gases as source streams and transports them through pipes, valves, heaters, coolers, and compressors. Natural gas usage was reduced by 12% in the refinery case study with integrated flare gas streams compared to the non-integrated flare gas stream case and by 27.7% in the base case without FGN, according to a FGN proposal. Therefore, the best FGN in this scenario shows an 89% reduction in the amount of flaring and a 90.6% reduction in the flaring emission penalty. (Nassim Tahouni, 2016).

H4: Flare Losses are impacted negatively by Positive technological integration in a refinery.

A small scale 5000 BPD of GTL technology was implemented along with using gas sweetening to ensure swift production of syngas and Fischer-Tropsch synthesis units. The economic results also demonstrated that the high price of crude oil was also a major factor in causing a benefit for this proposed model as with the high price of crude oil observed, additional solutions of converting methane into other refined usable fuels has ensured profitability (Santos, 2021). According to the technical and financial feasibility assessment, small-scale GTL facilities in Brazil that have a capacity of 1000 and 5000 BPD, respectively, will require 283,170 and 1,415,850 cubic meters of associated gas per day. Additionally, these reactors' respective IRRs with capacities of 1000 and 5000 BPD are 43% and 62% (Kaveh Zayer Kabeh, 2023). In a detailed study at the Asalooye Gas Refinery, three different methods were proposed to minimize disadvantages of flare gas combustion. The first method involves Gas to liquid Production which saves and produced about 48,056 barrels of oil per day. The second method revolves around electricity generation with a gas operated turbine which results in production of 2130 Mega Watts electricity. The third method involves a compression and injection method involving pipeline refineries which results in compressed natural gas with 129 bar pressure. This resulted in utilization of 365.5 MMSCFD which was otherwise flared and resulted in a massive loss. Economic evaluations are carried out keeping composition of flare gas as an important factor (M.R. Rahimpour, 2012).

H5: Type of Crude can play a moderating impact on flare losses by moderating the impact of Technological Integration in a refinery with Refinery operational performance acting as a mediating variable.

Research Model

Supply Chain Resilience and Preventing Product Loss in Crude Oil Refinery

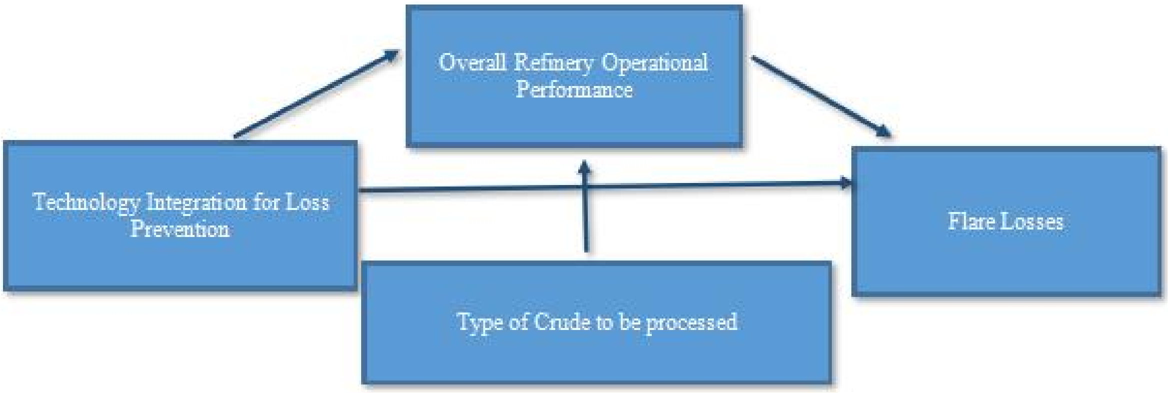


Figure 01: Research Model

Research Methodology

Population & Sample

Oil & Gas industry professionals with clear understanding of the working principles of refinery operations were selected from multiple different companies. The sample method used was non-probability sampling as due to the nature of our research it was important to strictly use professionals from the Crude Oil Refining industry. Although data set did involve individuals with a variable time of experience in the Crude Oil Refining Industry, the focus was to use individuals that would be better able to understand the relationship between individual variables.

Data Collection

Closed-ended questionnaires are used in this research which included 20 questions that contained a clear relationship between the individual variables and their relationship with each other using a logical step by step set of questions all interconnected to each other. Questionnaires were sent to almost 180 respondents via email and generated using Google Forms, from these 142 complete responses were received.

Data Analysis

Smart PLS v 4.0 software was used here with implementation of Partial Least Squares based on Structural Equation Modelling. The software used here has the ability to work on small sample size with a variety of data sets without compromising the model and simultaneously not making any assumptions about the basic data (Joseph Hair, 2022) . Multiple Regression analysis was used to observe the relationship between variables and latent constructs. This method is able to analyze complex models along with multiple functions in a smart analytical method in a single time. The main reason to use this method is its ability to draw a relationship between exogenous & endogenous variables and this in turn will help in research as it gives the researcher an advantage regarding efficiently estimating higher parameters (Joseph Hair, 2022).

Results

The below analysis shows values obtained during the research model along with the test variables. In the present study, the PLS-SEM 1 was selected for the current study. Measurement and structural model assessment were used to analyze the data. We analyzed and monitored the results of model by checking all individual items, discriminant and convergent along with internal consistency. We observed the indirect and direct relationship. Outer loading values of individual variables and reliability of individual items were measured and evaluated. There are two phases of the structure equation modeling namely measurement and structural model. All values and results were retained as the Primary data collected was strictly checked to conform to the criteria set out to obtain accurate results, therefore all 142 complete responses were used and applied.

Demographic Characteristics of the Study Respondents

Table 1 provides the complete demographics with regards to characteristics of the study participants. Candidates were segregated into variables including qualification, gender, age and tenure of the study participants.

Table 01: Demographic Characteristics

		Frequency	**Percent**
QUALIFICATION	Diploma	33	23.2
	Bachelors	46	32.4
	Masters	60	42.3
	PhD	3	2.1
	Total	142	100.0
GENDER	Male	120	84.5
	Female	22	15.5
	Total	142	100.0
AGE	20-30	26	18.3
	31-40	50	35.2
	41-50	54	38.0
	51-60	10	7.0
	61and above	2	1.4
	Total	142	100.0
TENURE	Less than 1 Year	7	4.9
	1 - 5 Years	25	17.6
	6 - 10 Years	33	23.2
	11 - 15 Years	41	28.9
	More than 15 Years	36	25.4
	Total	**142**	**100.0**

The table 1 depicts that the study participant having diploma were 33 out of 142, bachelors 46, masters 60, and PhD 3. The male respondents were 120 while the females were 22 which comprises of 84.5% and 15% of the total respondents respectively. As far as age of the respondents is concerned 26 of the total respondents were between 20 and 30, 50 were between 31 and 40, 54 were between 41 and 50, 10 were between 51 and 60 while only 2 were above 60 years of age. As far as their job tenure is concerned 7 of the total 142 respondents were having a tenure of less than a year, 25 were having 1 to 5 years of job tenure, 33 having 6 to 10 years, 41 having 11 to 15 years while remaining 36 were having job tenure of more than 15 years.

Descriptive Statistics

The table 2 shows the descriptive statistics of the items of the latent variables and the demographic variables. The mean for all items lies roughly around 3 while the standard deviation shows the values roughly around 1.

Table 02: Descriptive Statistics

	N	**Mean**	**Std. Deviation**
QUALIFICATION	142	2.23	.831
GENDER	142	1.15	.363
AGE	142	2.38	.913
TENURE	142	3.52	1.189
TI1	142	3.46	1.314
TI2	142	3.30	1.404
TI3	142	3.20	1.407
TI4	142	3.32	1.426
TI5	142	3.44	1.495
ROP1	142	3.32	1.366
ROP2	142	3.04	1.350
ROP3	142	3.01	1.404
ROP4	142	2.92	1.451
ROP5	142	2.7958	1.41691
TCP1	142	2.93	1.372
TCP2	142	3.64	1.081
TCP3	142	3.58	1.157
TCP4	142	3.72	1.211
TCP5	142	3.7113	1.13975
FL1	142	3.42	1.285
FL2	142	3.29	1.335
FL3	142	3.25	1.296
FL4	142	3.3028	1.20277

FL5	142	3.4085	1.32705
Valid N (list wise)	142		

Measurement Model

The model below provides the outer loading of the all items included in the study model. The initial model of the study has total 20 items. The outer loading of the items should be greater than 0.7. This ensures the convergent validity of the constructs.

Table 03: Item Loadings

Construct	Items	Loading
Flare Losses	FL1	0.824
	FL2	0.646
	FL3	0.771
	FL4	0.769
	FL5	0.805
Overall Refinery Operational Performance	ROP1	0.645
	ROP2	0.663
	ROP3	0.833
	ROP4	0.828
	ROP5	0.759
Type of Crude to be Processed	TCP1	-0.185
	TCP2	0.739
	TCP3	0.865
	TCP4	0.819
	TCP5	0.839
Technology Integration for Loss Prevention	TI1	0.850
	TI2	0.891
	TI3	0.803
	TI4	0.836
	TI5	0.868

The table 3 shows that all four constructs have five items each and their values are above the suggested value of 0.7 however four of the items have value less than 0.7 i.e. FL2, ROP1, ROP2 and TCP1. We remove the three items FL2, ROP1 and TC1 as removing ROP1 increased the value of ROP2 so we did not remove ROP2 and re-run the measurement model. The final model with reduced (17 items) is presented as follows.

Figure 02: Model

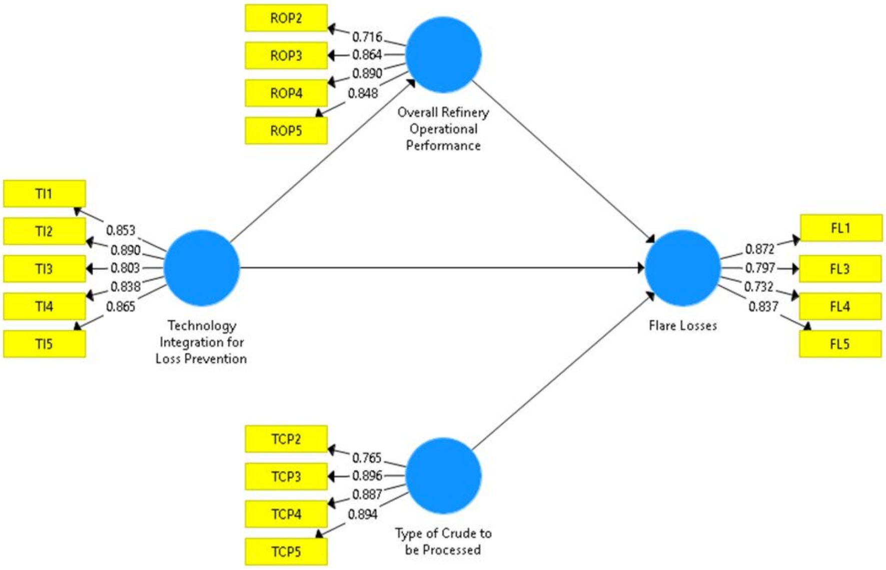


Figure 1 clearly shows the loading of each item presented above is greater than the suggested value of 0.7 hence we can proceed with the further analysis. Along with items loadings following values also provides the convergent validity. The tables 4 provides the results of the measurement model.

Table 04: Construct Reliability and Validity

	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
Flare Losses	0.825	0.884	0.658
Overall Refinery Operational Performance	0.852	0.9	0.693
Technology Integration for Loss Prevention	0.905	0.929	0.723
Type of Crude to be Processed	0.889	0.92	0.744

The above table provides the results of reliability and validity of the construct the value above 0.7 for Cronbach's alpha is good to go and same is the case with the composite reliability. The AVE should be greater than 0.5. All the values meet the provided criteria hence the convergent validity is ensured. See table 4 above.

Figure 03: Average Variance Extracted

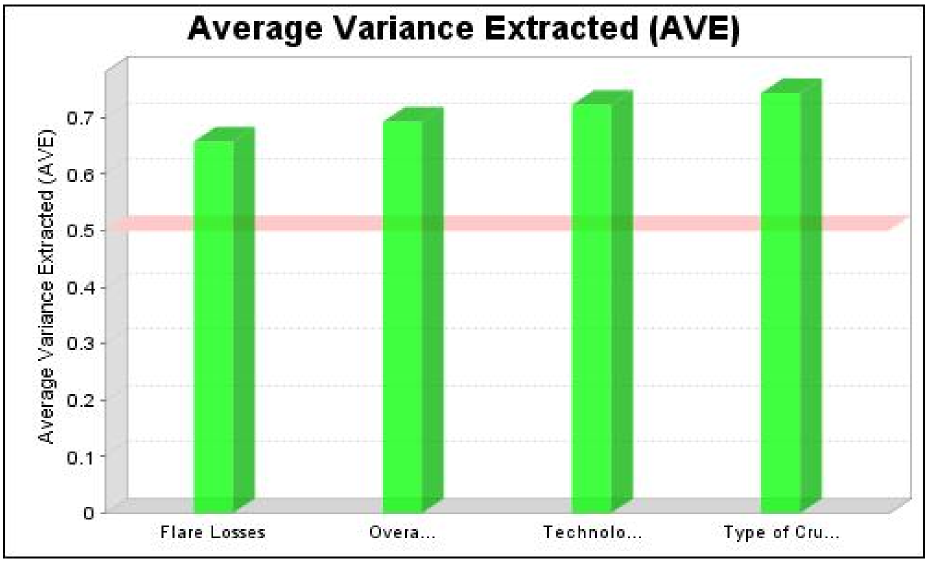
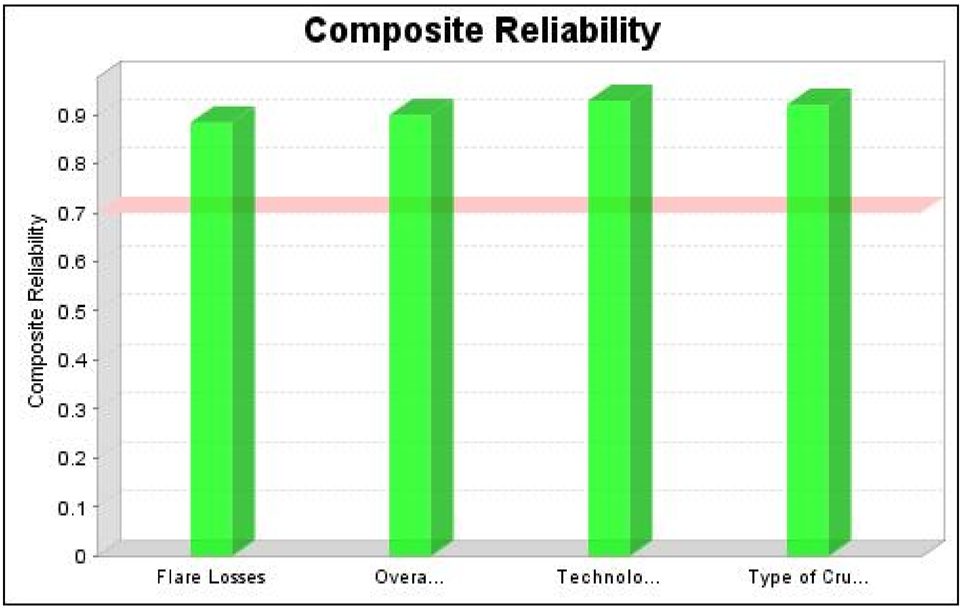


Figure 04: Composite Reliability



Discriminant Validity

The degree of the difference between constructs and measures can be evaluated by discriminant validity Discriminant validity makes sure that the items are not measuring some construct other than their respective construct. The current study uses three different ways to ensure discriminant validity of the model i.e. Fornell Larcker criterion, cross-loading and HTMT.

Table 05: Cross Loadings

	Flare Losses	Overall Refinery Operational Performance	Technology Integration for Loss Prevention	Type of Crude to be Processed
FL1	0.872	0.271	0.386	0.195

FL3	0.797	0.218	0.243	0.232
FL4	0.732	0.209	0.278	0.257
FL5	0.837	0.196	0.365	0.218
ROP2	0.181	0.716	0.225	-0.101
ROP3	0.274	0.864	0.318	-0.119
ROP 4	0.202	0.89	0.162	-0.16
ROP5	0.239	0.848	0.203	-0.027
TI1	0.36	0.225	0.853	0.274
TI2	0.358	0.257	0.89	0.358
TI3	0.334	0.274	0.803	0.21
TI4	0.197	0.193	0.838	0.372
TI5	0.386	0.246	0.865	0.326
TCP2	0.112	-0.099	0.32	0.765
TCP3	0.289	-0.08	0.327	0.896
TCP4	0.252	-0.097	0.356	0.887
TCP5	0.234	-0.153	0.244	0.894

The above table 5 shows the cross loadings of the items corresponding to their respective constructs. Which shows that all the relevant items are well loaded against their respective constructs and not having a better loading values against the other constructs providing evidence for the discriminant validity.

Table 06: Fornell Larcker

	FL	ROP	TI	TCP
Flare Losses	**0.811**			
Overall Refinery Operational Performance	0.277	**0.832**		
Technology Integration for Loss Prevention	0.397	0.285	**0.850**	
Type of Crude to be Processed	0.276	-0.121	0.357	**0.862**

The above table of the Fornell- Larcker Criteria shows that all the values presented in the diagonal are above their corresponding values in the respective column and row. This is the evidence that the discriminant validity is ensured.

Table 07: HTMT

	FL	ROP	TI
Overall Refinery Operational Performance	0.32		
Technology Integration for Loss Prevention	0.44	0.306	
Type of Crude to be Processed	0.301	0.146	0.408

The above table of HTMT shows that all values are below 0.85 which shows that the discriminant validity is presented in the model. After meeting the all criteria for convergent and discriminant validity. The data analysis is proceeded to the structural model which will help in testing the study hypotheses.

Structural Model

Before moving to the path analysis, we first examine the multi collinearity of the variables so that the results are free of multi collinearity issue. The multi-collinearity is tested based on the VIF values. The VIF table is presented below.

Table 08: Multi collinearity Testing

	Flare Losses
Overall Refinery Operational Performance	1.165
Technology Integration for Loss Prevention	1.332
Type of Crude to be Processed	1.306

The above values of VIF which are very low and around 1, shows that there are no multi-collinearity issues in the model. The strict maximum value for VIF is 5. However our model does not have any such value greater than 5.

Table 09: Results of Direct Effects

Path	Coefficient	T Values	P Values	Decision
ROP →FL	0.233	2.752	0.006	Supported
TI → FL	0.264	2.707	0.007	Supported
TI → ROP	0.285	3.895	0.000	Supported

Table 10: Results of Indirect Effect (Mediation)

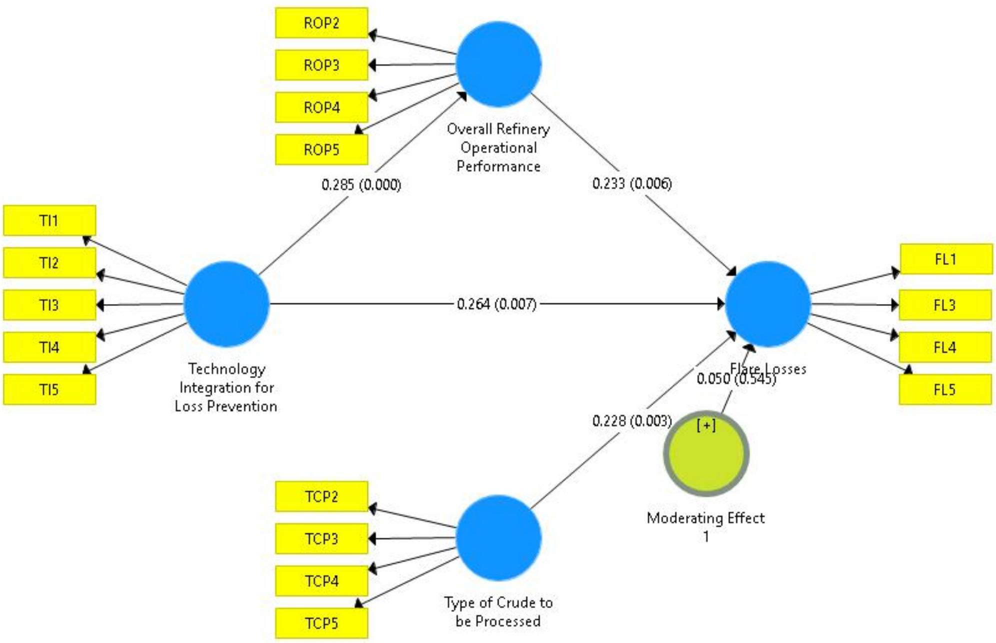
Path	Coefficient	T Values	P Values	Decision
TI → ROP → FL	0.066	2.113	0.035	Supported

Table 11: Moderating Effect of (Type of Crude to be processed)

Path	Coefficient	T Values	P Values	Decision
Moderating Effect of (TCP) TI → FL	0.05	0.605	0.545	Not Supported

The above tables 9, 10 and 11 provide the results of direct, indirect (mediating) and moderation analysis testing hypotheses 1 to 5 of the study. The results depicts that hypotheses 1 to 4 which are direct and mediating analysis are supported having p-value less than 0.05 while the hypothesis 5 did not found to be supported having a values of 0.545 which is greater than 0.05.

Figure 05: Structural Model Showing Direct, Mediating and Moderating Relationships



The coefficient for determination (R2) measures the model's predictive accuracy. R2 value ranges from 0.081 - 0.227 while the F2 value ranges from 0.05 to 0.089 which goes from small, medium to large. The Stone-Geisser test was used to assess the research model's predictive usefulness when blindfold procedures were included in the analysis. The PLS-SEM's fitness is assessed using this test. See table 12.

Table 12: R-square and F-Square

R-Square	**Dependent Variable**
0.227	Flare Losses
0.081	Refinery Operational Performance
F-Square	Dependent Variable
0.060 ROP	Flare Losses
0.068 TI	
0.051 TCP	
0.089 TI	Refinery Operational Performance

Discussion

This study examined the mediating role between Refinery Operational Performance in defining Integration of Technology for loss prevention towards having an impact on Flare losses. Various literature was used here to establish a relationship and explore ideas on how there could be a possibility in determining the aforementioned Relationship among the variables. First a relationship was introduced between Refinery Operational Performance as a mediator between

Technology Integration and Flare Losses. Literature expanded a relationship between Technology Integration and Refinery Operational Performance as a mediating effect. Secondly, Flare losses were explored as a dependent variable in relationship with Refinery Operational Performance which was used as a mediating factor. Thirdly, literature was used to observe if Types of crude had a moderating impact on flare losses as a dependent variable along with if it moderated Technology Integration as an independent factor. The results showed that Technology integration had a massive impact as an independent factor.

Introduction of Flare recovery systems which proposed viable technologies were checked thru a feasibility study method and assessed accordingly. Their installation meant that flare losses could have about seven different uses (Ali Mohammadi Dinani, 2023). Furthermore, another aspect of this technological amendment was also covered by him indicating that the payback period for the entire project was about 48% of the max payback period which is higher than the minimum acceptable rate of return of the project. Another method involving Gas-to-Wire (GTW) method carefully calculated the impact of an alternative solution. Electricity production via turbines could help utilize the flared gas by converting the heat into electricity and hence being used by Refinery operations or supplied elsewhere in the national gridlines. Here, work was also done on the sizing of the GTW system to find the optimal conversion between gas to electricity and the results proposed a maximum possible potential of Reduction in flare losses which went as far as to calculate the percentage reduction in flare losses for different countries including but not limited to 83.11% in Algeria and 55.76% in the UAE. This reduction is calculated not just for a single refinery but on a national level indicating how almost all refineries have the option to use such an upgrade and henceforth, being able to massively reduce flare losses by incorporating technological integration of newer hardware affecting operational performance of a refinery as a mediating role towards reduction in flare losses (Orisaremi et al., 2021).

The routine operational aspects of a refinery have a massive mediating role in enabling Integration of technology to work towards reduction in flare losses. This was calculated and confirmed by monitoring and changing the Flare cooled power cycles that were used before electricity production took place using fare gasses as a fuel for turbines. Two different cycles were involved and manipulated to obtain the best results. The first one involved adding natural gas into flare gas mixture while the second one involved using flare gases as a means to reheat the exhaust flow of the primary heater via partial expansion within a high pressure turbine. An extensive analysis consisting of energetic, exergo-economic and exegetic optimization was done to prove whether this could have any possible impact and six different flare gas samples were used indicating how eventually the type of flare gas can have a moderating impact on flare gas losses. A result was achieved when two different systems were used towards power generation of a 50 MW system and a 100 MW system. A unique method used here involved isentropic efficiency as part of the equation which symbolizes how in the real world we are not always faced with and isentropic power equation since not all heat transfer processes are adiabatic not reversible. This model showed that at higher electricity power generation capabilities the efficiency of flare to electricity conversion was increased indicating how there could be a massive potential to utilize flare gases towards generation of electricity thereby reducing the burden of electricity generation from other resources. Furthermore, this experiment was conducted on sweet to bitter samples of flare gas and the results showed that the sweeter the gas the better and more superior performance it had towards being used for electricity conversion. The overall operational performance was used as a mediating factor here as removal of Nitrogen and Sulfur compounds from crude oil sample meaning increasing the workflow and cycles that the flare gasses have to go thru. Therefore, a sweeter sample of crude oil reduced the burden of the refinery equipment to first clean and sweeten the flare gas and then utilize it elsewhere thereby massively impacting flare loss via monitoring the steps and therefore the cost and time constraints involved in refining crude oil into various components.

The model proposed that eventually type of crude is a deciding factor when taking flare losses and flare emission into account but additionally also helped understand how to reduce the cost of refining crude since it also factored in the samples of flare gas being used in the conversion process (Ahmad K. Sleiti, 2022). Isentropic efficiency of a turbine was used here which is a detailed research model in itself as via experimentation it was found out that for two turbines used in experimentation, the efficiency was increased from 26.6% to 39.9% and for the other turbine the results indicated efficiency increasing from 50% to 90%. This shows how a possible upgrade in the technological advancements in a refinery could also involve changes in the turbine system which would better utilize the flare gas and hence producing more power for the same BTU equivalent of flare gas used (Ibrahim Dincer, 2018).

When elaborating on the moderating impact of type of flare gases, a model by petri went as far as to provide a solution that would eventually result in zero routine flaring and achieving an implementable 19.32% rate of return for any physical additional technological advancements required in the refinery when installing new hardware to cater to the cost of implementing a new system. The changes proposed and clearly identified lapses in the previous system that were easily overcome via the mediating impact of operational performance in a refinery. Implementation of a Fractionator, Compressor, gas separator, absorber and stripper increased the composition of Saleable LPG & LNG produced in the refining process and thereby reducing the volume and mass of the flare gas produced. Furthermore with the remaining flare gas utilization of flare gas in a gas engine generator was tested and about two units of 800 kW were used and were successfully tested at 80% efficiency producing 1280 kW of energy by improved utilization of flare gas. This method increased the economic value of flare gas since not only was there a massive removal of components from the flare gas, additionally, the remaining was utilized in electricity generation reducing diesel consumption by about 4656 Liters per day for which the flare gas was utilized (Pietrosemoli & Rodríguez-Monroy, 2019).

Managerial Implications

This entire study was focused on finding workable solutions towards reduction in Flare losses by either reducing the flare gas produced or further utilizing the flare gas to produce electricity which would be otherwise be wasted necessary volume of Diesel would be wasted and hence for the it would result in lower greenhouse effects. Obstacles involved in the implementation of technological advancements included initial cost of investment and payback time period. Developing countries will need time to be able to implement such technologically advanced projects as no matter how short the turnover rate or the cost benefit analysis, the initial cost of installment of additional hardware being incorporated into a refinery will require a significant capital cost due to compliance with newly emerging industry standards (Orisaremi et al., 2023).

New project installation would also require support from government organizations including reducing the cost of implementation of new equipment. The major impact of delayed Letter of Credit along with higher taxes on import hinder the implementation of new hardware that would be used in reduction of flare losses via either conversion of flare gases to electrical energy or reduction of flare losses by reducing flare gas production (Emeka Ojijiagwo, 2016).

Conclusions

The entire research was focused on reducing flare gas losses in refinery operations. The reason for Flare losses have been understood to be due to Integration of Technologically advanced hardware that would be able to either reduce production in flare gas or otherwise utilizing flare gas to produce electricity and heating energy that would otherwise be produced via wastage of precious refined products of crude oil. The overall benefit that was observed of this research is that there is abundant room in refineries around the world to reduce flare gas losses by both reduction of flare gas production and then utilizing the produced flare gas to generate electricity using the most Isentropic efficient methods. Our method to better understand and conclude the impact of Technological Integration into a refinery by optimizing the daily Operational

Refinery Performance does have a positive role in mediating Crude Losses. Types of crude was shown to have a moderating impact when determining the flare losses. It was observed that flare losses are a dependent variable and can be significantly minimized and reduced via new technologically advanced hardware integration. When using the method of analysis that we followed we were able to find in detail implementation of technological advances in different refineries and were able to successfully conclude that these technologically advanced measures did indeed help in mitigating and reducing flare losses.

Limitations & Future Research Directions

Our obstacles in terms of limitations include that refineries are massively faced with the problem of delayed letter of credits, high taxes from the local governments and long approval times in implementing and installing new hardware. These three obstacles have three major impacts separately. Delayed letter of credits generally causes a problem in terms of delayed contract times and bad reputation between client and customer relations in terms of industries since this would delay the timeframe of the project thereby increasing the cost of implementation of a new project. High taxes cause a massive hike in price of the project since they increase the cost of the project and can result in unpredictable increase in cost of project initiation. This would disrupt all calculations and improvements involved in project approval and initiation. Due to local government policies there are at times hindrances in getting approval for import and approval of installation of new hardware that would disrupt the teams involved in installation of a project since that would increase the timeframe needed to install and successfully test out these new projects. Since projects involve multiple teams of different departments working together to successfully implement a new project, hindrance in availability of hardware and equipment or parts of an equipment would cause delay in project time frame. Future work towards development of a system that would help in finding an even better solution should involve meetings between all stake holders so that all aspects of technologically advanced equipment would be carefully monitored to run in the most optimum manner. Studies have shown that power generation has been termed as an appropriate solution towards mitigating Flare gas loses as they consider the social, environmental and economic performance of a refinery. It was concluded that power generation has strong dependency on the type of flare gas used for power generation and therefore future studies can go to show how further sweetening of crude oil is to be worked upon since its benefits can be seen towards economic benefits to the refinery along with assisting the refinery reach its environmental targets and objectives.

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