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A Multi-Criteria Decision Analysis (Mcda) In A Petroleum Terminal Pipeline Network for Outbound Flow Path Selection

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Abstract

The route selection operation of a petroleum product storage depot is a daily task and requires precision. Challenges arising from wrong route selection are varied and affect the operations of the depots. This research presents the application of the multi-criteria decision analysis (MCDA) in petroleum terminal pipeline network for outbound flow path selection. This was motivated by the need to optimize the operation of route selection for outbound flow in most petroleum depots which is usually done manually by just choosing any of the available routes without consideration for distance and steady flow of the product due to available quantity in the tank. To achieve this, some personnel of the Rosa Mystica Energy depot were interviewed and basic data for the system development were collected. A software prototype (model) was adopted for the MCDA system to determine the best flow path for outbound petroleum product using a multi-criteria decision analysis (MCDA) approach. The application was developed on the PhpStorm IDE and has an SQL database running on an apache web server. The system was tested on a mobile device and on a personal computer and the result gotten shows that the idea of automating the decision of selecting route for product flow can greatly improve pump efficiency as there is sufficient supply of product to the pump during operation and the time taken to load trucks will equally be reduced. It is recommended that a more robust route selection application should be developed and deployed for enterprise use.

Keywords: *Multi-criteria, Decision, Petroleum, Pipeline, Network, Optimal.*

Introduction

Petroleum is an essential commodity for virtually every economy as it serves as a vital source of energy in driving operations in various industries. The transfer of petroleum products from oil fields to consumers involves various forms and stages of pipeline networks. Research has shown that there is a 3% loss of the total petroleum products that flow through pipelines due to evaporation (Hasan *et al.*, 2018).

Pipeline Systems have been identified as a very suitable way of transporting oil, gas, and petroleum products as they are the most cost-efficient way of transferring fluid over long distances (Yildirim *et al.*, 2013). Due to the impact of transporting petroleum products on national security and the economy, it has become necessary to create more reliable and affordable methods of transferring these products (Balogun *et al.*, 2012). Pipelines are expected to provide an efficient, cost-effective, and environmentally friendly mode of transport of petroleum fluids. Therefore, there is the need for a thorough planning process that takes into consideration the route of the pipeline in such a way that time and operating expenses can be saved in the long run (Gyabeng, 2020).

On a much smaller scale, petroleum depots domiciled in several parts of the country run petroleum products through pipeline networks to move the petroleum products from several tanks into a designated tank for transportation. The petroleum depots receive the products through the water ways from petroleum vessels. The products from the vessels are pumped using some high power pumps to the depot's storage tanks through a network of pipelines after every regulatory check have been done. These checks include navy clearance, port health officers' inspection of the vessel, the Nigerian Port Authority (NPA) official's inspection and the Department of Petroleum Resources (DPR) product sampling and lab analysis.

In a depot, the volume of the product received into the tanks is check for conformity with the expected volume from the vessel. Any disparity in this volume will result in investigations. This investigation will involve pipeline inspection for any leakage or vandalization. Other investigation could involve inspecting the vessel for any hidden compartment where products could have been diverted into. Once the volume of the product has been confirmed, the sale of the product will begin.

Registered customers who are interested in purchase of the product from the depot will present a license from the Department of Petroleum Resources (DPR) to the depot's commercial department stating the requested volume. After the license has been verified, the customer is then given a voucher to proceed to the bank for payment. The customer returns with proof of payment which will then be verified with the bank. After the payment has been verified, the customer's name, truck number and quantity are then batched for loading. The product is being sold in the following quantity: 33,000litres, 40,000litres, 45,000litres and 60,000litres unless otherwise necessary. All the batched customers are then listen on a daily manifest which is forwarded to the safety department, security department and operations department. The safety department takes care of the inspection of the truck before and during the loading operation. Any truck that fails to meet the safety standard is rejected and the owner will have to apply for a change of truck. The security department ensures that only trucks on the manifest enter the loading gantry after the necessary security checks. The operations department takes care of the actual loading activity.

In the process of transferring the petroleum product from several tanks into the final destination, the operations personnel at the depot are tasked with the challenge of identifying the best path the products have to take that will provide the shortest path and most optimal flow. This means deciding on which valves to close or open. If the right decision is not made in determining the most appropriate flow path for the petroleum product, the flow from one point of the network to another may not be steady. This would result in the lack of steady flow of the petroleum products getting to the pump from different tanks. A lack of steady flow means more power consumption and a longer loading time.

To this end, this study aims to create a system that applies a Multi Criteria Decision Analysis (MCDA) in a petroleum terminal pipeline network for outbound flow path selection. To achieve this, the following are the main objectives:

i. To determine the essential terminal operation processes that lead to outbound flow using a requirement gathering session and identify the key factors for the decision-making model that determines the optimal outbound route.
ii. To derive the decision-making model for optimal outbound flow using a multi-criteria decision analysis approach.
iii. To develop the pipeline route selection system to automate the route section decision.
iv. To test and validate the decision-making model using the developed pipeline route selection system.

Related works

Over the last decade, numerous attempts have been made to automate the route-planning process using Geographic Information Systems (GIS) technology and Multi-Criteria Decision Analysis (MCDA). A review of several papers put forward that these methodologies are still being at a probing stage. Yildrim and Tomuralioglu (2011), compared the path-finding method for oil and gas pipeline traditional procedure. In their study, they proved that the path designed by using GIS is 14% cheaper than the path coupled with the traditional technique and also confirms GIS software as more user-friendly than other software (Arabi, 2018). During the study conducted in Turkey on Optimization Model for pipeline routing based on GIS and MCDA approach suggested at the end of the study that the route defined using raster network analysis techniques over the developed model reduces project cost by 23%, pollutes the environment at a lower level, and is more appropriate from a sociological perspective (Gyabeng, 2020).

In some studies, current routes have been optimized and the cost of routes selected by using conventional methods (economic, social, and time costs) are compared with the costs of the routes selected by using GIS-based models (Rylsky, 2004). The application of AHP in oil and gas pipeline route selection has yielded tremendous results since it has transformed traditional qualitative analysis to comprehensive qualitative and quantitative analysis (Balogun *et al.*, 2013; Kiker *et al.*, 2005). Also to save time, money, effort, and fuel consumption during Selection of Road Alignment Location in Kano-Nigeria, GIS and Analytical Hierarchy Process (AHP) model results show that the Hybrid theme LCP is the most economical, suitable, and has the shortest travel distance of 37.31km (Sunusi, 2015).

An optimal oil pipeline route was generated using GIS analysis and spatial modelling incorporating multi-criteria decisions with environmental, engineering, technical, and social factors being the key criteria (Macharia &Mundia, 2018). In comparing the existing pipeline routes to the proposed pipeline routes for Keystone XL, Nebraska state USA the least-cost paths accurately detail routes that are amazingly similar and effective in providing a path from

the documented source and destination points within Nebraska (Huseynli, 2015).
In addition to these researches conducted by Yildirim & Yomralioglu (2011), Iqbal, Sattar & Nawaz (2006), a variety of other studies have been performed to choose the most suitable route between many routes which replaces the traditional approach of route selection. Different implementations have been carried out in these studies using GIS techniques. Some routing experiments were also performed using only one or a few of the important factors influencing a selection of a pipeline path.

Methodology

A multi-objective optimization approach that yields vector outcomes (length of pipe, volume of tank and quantity of product requested) has been adopted in this study. The programming approach adopted is non-linear because the constraints are non-linear. The Prototyping Model was adopted for the development process in this research. This development process model was selected because an initial phase of the final application and not the entire application was to be developed. Also, this application is being developed for the purpose of conducting a feasibility study that would help determine how possible it is to optimize the best flow path for outbound petroleum to take using a multi-criteria decision analysis (MCDA). The software development lifecycle makes it possible for the potential users of the system to see how well the system will be able to support their work while also arriving at new ideas of requirement specifications for subsequent development projects. Fig. 1 illustrates process of the prototype development of system

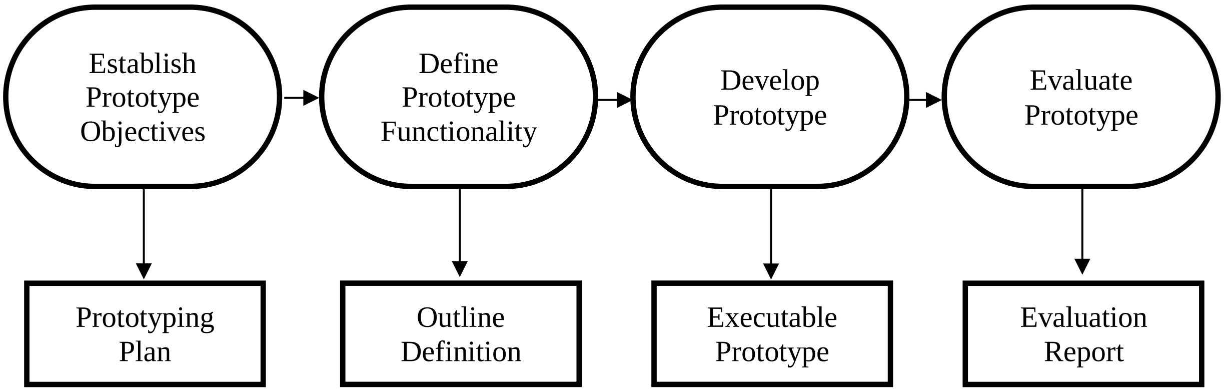

FIG. 1: The process of prototype development

The parameters that affect the decision-making process were identified. Interview was conducted on the personnel of the ROSA MYSTICA ENERGY Company to understand operations in the working environment and to gather data that describe the outbound flow of petroleum from the tanks to the dispatch points. Features and functionalities were decided upon for the development of the Pipeline Route Selection System. The expected features and functionalities of the initial prototype of the system were first modeled and then implemented using PHP, JavaScript, HTML and CSS programming languages on the Phpstorm integrated development environment (IDE) with the Pico CSS framework. An executable prototype was created at the end for verification and validation based on the objectives defined from the onset, the features, and the functionalities outlined by the prospective users of the system.

The prototype was validated by the users to see if the actual functionalities of the MCDA system matched the requirement specifications detailed at the beginning of the process. A user-centred testing approach was adopted to evaluate the prototype. This was done in two ways:

1. Task-based user study
2. Peer group interview

For the task-based user study, prospective users were invited to carry out specific tasks on the system while the time spent on each task was measured as a way of assessing the ease-of-use and user friendliness of the system prototype.

A petroleum terminal owned by ROSA MYSTICA ENERGY Company located at Calabar Free Trade Zone was used as the case study for this research work. An interview was conducted with staff of the company to understand how business operations take place prior to this research study. It was discovered that customers of this facility are primarily petroleum marketers who bring their trucks to purchase fuel. Below is a step-by-step process of the purchase cycle of each transaction:

1. The customer presents a Department of Petroleum Resources (DPR) certificate of registration.
2. An approved customer is given a voucher for the volume of petroleum product requested for (e.g. 33,000 litres).
3. The customer makes payment at the bank.
4. Customer presents evidence of payment and the customer's truck is batched in the manifest.

5. The truck is then inspected by the safety team before loading permit is granted.
6. The truck moves to the loading gantry (dispatch platform) where the amount of fuel paid for is loaded into the tank of the truck.
7. The cycle is repeated for other customers.

A schematic diagram was received from a staff of the company that demonstrates the number of petroleum tanks at the petroleum depot and the pipeline network that connects them to the dispatch points. This schematic diagram is shown in Figure 2.

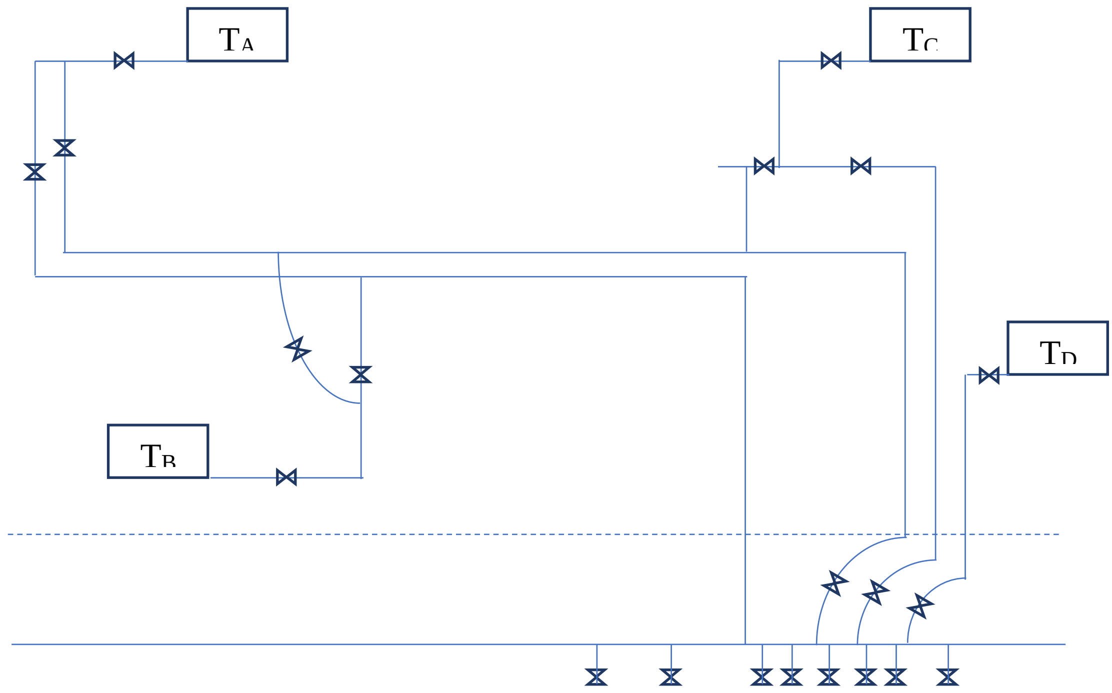

FIG. 2: Schematic diagram of the Pipeline Network at the Petroleum Terminal

The pipeline network in the petroleum terminal used as a case study as presented in FIG. 2 is made up of four tanks (T_A, T_B, T_C, and T_D).

From the initial requirement gathering, three factors were identified as responsible for selecting the best route for outbound flow of petroleum products from the tanks into the purchasing truck. These factors were identified to be the length of each pipeline route from each tank, the current volume of petroleum products in each of the four (4) tanks and the quantity of petroleum products the terminal has decided to dispatch. Considering these three (3) major determining factors, a multiple weight model had to be determined to support the GIS-based MCDA approach adopted with its route selection process with the following attributes.

1. Length of pipeline – L
2. Volume of product – V
3. Requested quantity – R

Table 1 shows the available routes modeled and their lengths

Table 1: Available routes and their lengths

Route	Lengths (M)
A1	75
A2	90
B1	69
B2	72
C1	62

C2	67
D1	38
utD2	39

The weights of the various attributes were determined using the Analytic Hierarchy Process (AHP)

Using the pair wise comparison matrix according to Saaty (1980) and the ordinal scale (1 – 9);

$C_p = \frac{n-1}{2}$ (pairwise comparison formula) - - - (1)

Where: C_p is number of comparisons and n is number of criteria. Tables 2, 3 and 4 respectively show the normalized pairwise comparison matrices.

Table 2: First normalized pair wise comparison matrix

	L	V	R
L	1	7	4
V	0.14	1	5
R	0.25	0.20	1

Table 3: Second normalized pair wise comparison matrix

	L	V	R
L	1	7	4
V	0.14	1	5
R	0.25	0.20	1
SUM	1.393	8.2	10

Table 4: Third normalized pair wise comparison matrix

	L	V	R
L	0.72	0.85	0.4
V	0.10	0.12	0.5
R	0.18	0.02	0.1

The criterion weights of the parameters are presented in Table 5.

Table 5: Criterion weights of parameters

	L	V	R	Weights(w_j) = Avg of each Row
L	0.72	0.85	0.4	**0.657**
V	0.10	0.12	0.5	**0.24**
R	0.18	0.02	0.1	**0.1**

As shown in Table 5, the weights of the various criteria were gotten as:
L = 0.657
V = 0.24
R = 0.1
Before the system programming phase began, the three criteria were classified into the cost attribute and benefit attribute groups. Length of the pipeline (L) is a cost attribute, while Volume of product (V) and Requested quantity (R) are both benefit

attributes. Benefit attributes are those criteria in which the more the value, the better, while the cost attributes are those criteria where the lesser the value, the better. The various attributes were then normalized using the linear-scale transformation (sum) method thus:

For benefit attributes $r_{(ij)} = X_{(ij)}/\sum X_{(ij)}$ --- (2)

For cost attributes $r_{(ij)} = (1/ X_{(ij)})/ \sum(1/ X_{(ij)})$ --- (3)

Where r = normalized value

X = Ordinal scale value of the ith row and jth column from the pair wise comparison matrix.

The global score (preference score) is gotten using the weighted sum model thus:

$V_{(Ai)} = \sum_{j=0}^{n} w_j r_{ij}$ --- (4)

Where V = Global score (weighted sum)

A = Alternative (in WSM, the score of an alternative is equal to the weighted sum of its evaluation ratings, where the weights are the importance associated with each attribute).

W = weight

The modelling process transforms the processes on the system into models. In the design of the Pipeline Route Selection System, it was taken into consideration that there will be one category of users that will be responsible for data entry and a request for the best route for outbound flow.

The Use-Case scenarios of the system are described as follows:

1. The user opens the installed application on a work station or personal computer device.
2. The user views the dashboard of the application
3. The user enters distance of each tank from the dispatch point for each path
4. The user enters current volume of petroleum in each tank for each path
5. The user clicks on 'Update Tank X' for each path
6. The user enters the requested amount of petroleum
7. The user clicks on 'Get Recommendation'
8. The system provides the selected tank for outbound flow (for single tank)
9. The system provides the best two tank combinations for outbound flow and the best route in order of preference based on the distances of the paths.

The architecture of the the pipeline network at the petroleum terminal is illustrated in Fig. 3.

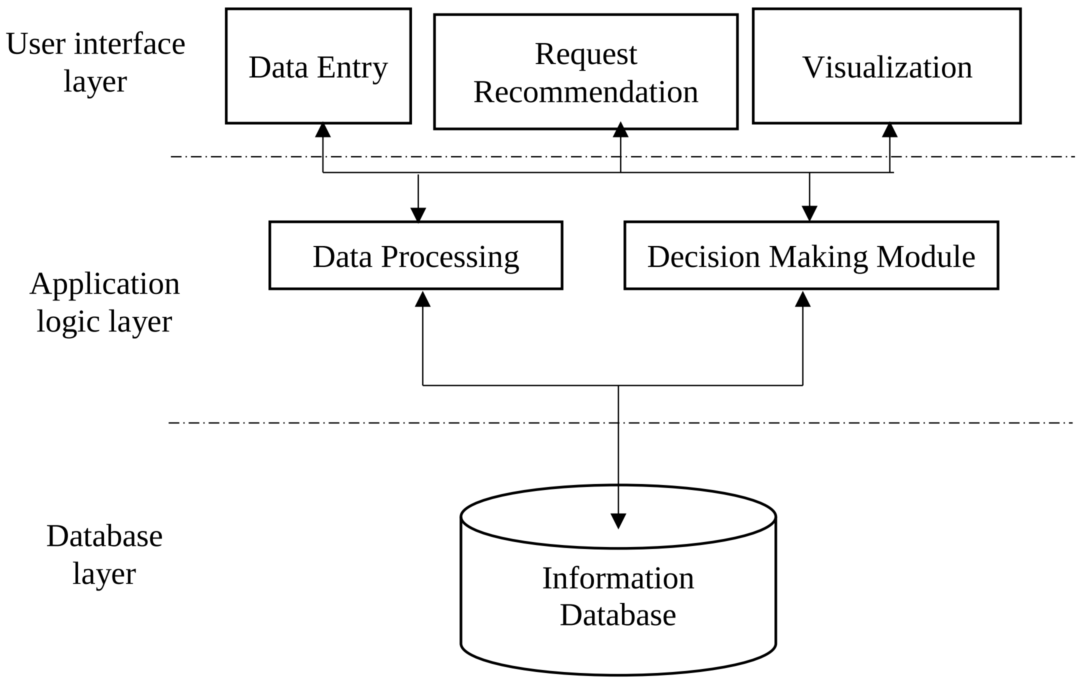

FIG 3**:** Architecture of the the pipeline network at the petroleum terminal

Results and Discussions

The screenshot in FIG. 4 shows the user interface of the Pipeline Route Section system when the user has to enter the required data. The parameter for the pipeline distance is a onetime requirement. This is because the distance of the tank to the pump is fixed. On the other hand, the content quantity is a variable data as the quantity of the product in the tank will always vary depending on truck out and vessel receipt.

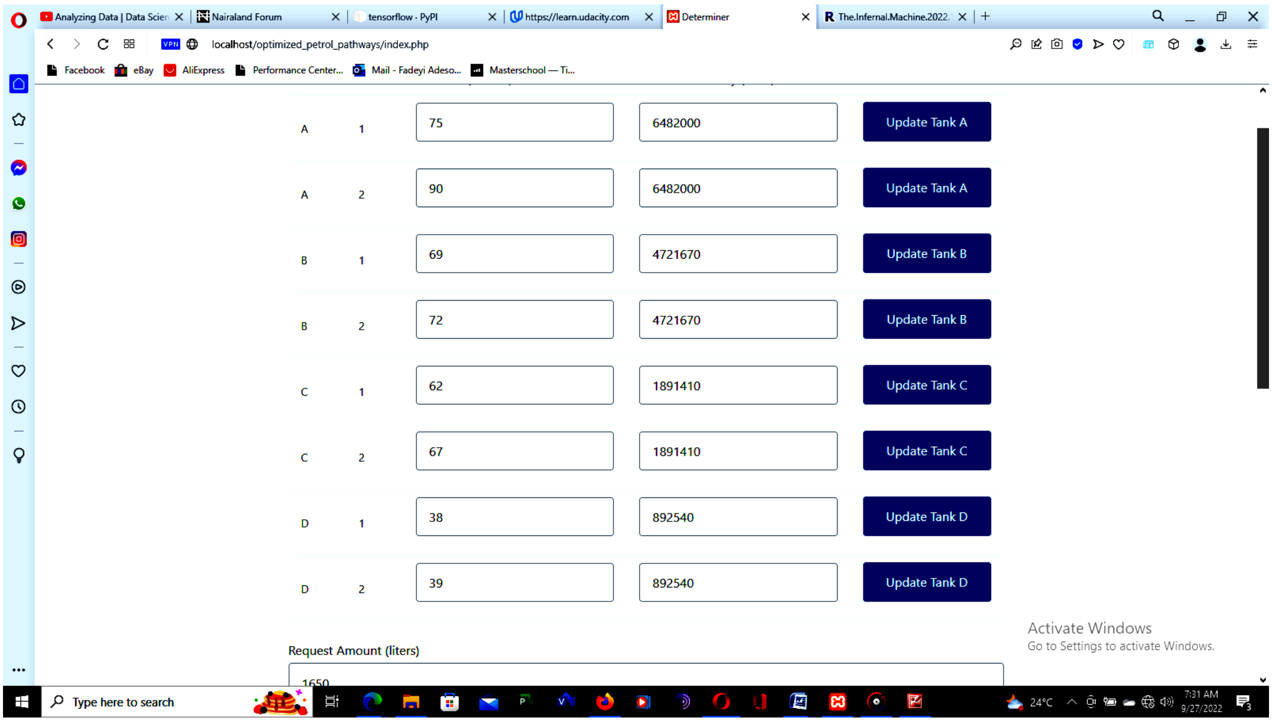

FIG. 4 Data Entry Section of the Pipeline Route Selection System

The screenshot in FIG 5 shows the recommendation request and visualisation section of the system. Here the quantity of product to be trucked out is entered and a recommendation is requested. The system displays the result as recommendations, giving all the available options and their corresponding cost in terms of distance.

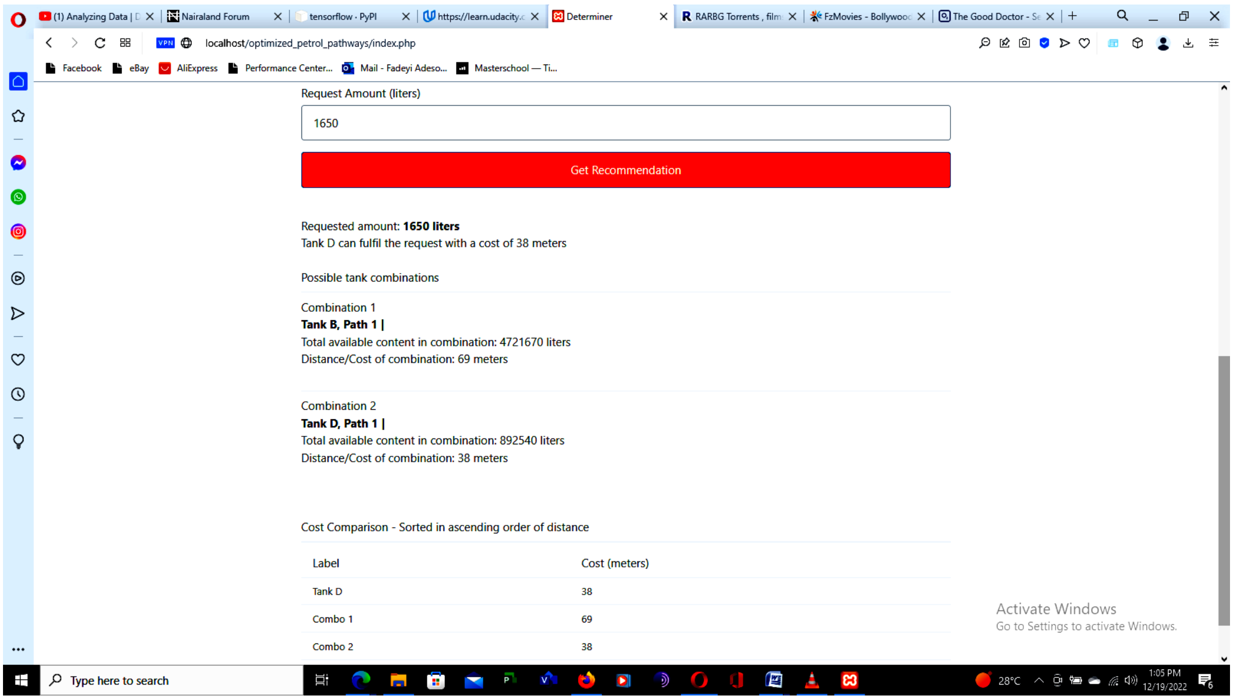

FIG. 5: Recommendation Request and Visualization Section for the Pipeline Route Selection System

Table 6 displays the user assessment evaluation of the system tested.

TABLE 4: User assessment evaluation results of the Pipeline Route Selection System

Participant	**Functionality (%)**	**User Interface (%)**	**Usability (%)**
Participant A	94	80	85
Participant B	75	80	90
Participant C	60	84	59
Participant D	60	80	60
Participant E	80	80	70
Average Score	**74**	**81**	**73**

It was observed from the average scores obtained from the users' evaluation of the system that the participants viewed the system as having the capability to help them determine the best pipeline route as far as outbound flow was concerned, and also to be good in terms of the functionality and usability. The evaluation also found the system to be very good in terms of the user interface.

Conclusion

The resulting Pipeline Route Selection System which has been developed in the course of this research study will address the difficulty petroleum product distribution staff have in determining the best path for outbound flow at any given time that will be most cost-effective. With this application in place, less time will be spent in supplying customers with petroleum products. It will also help to reduce cost of operation as the pumping machines will work for much lesser periods since it receives sufficient supply of products. This will eventually go a long way to increase the company's profitability. This research study has successfully demonstrated how a Pipeline Route Selection System using Multi-Criteria Decision Approach (MCDA) makes pipeline route selection in a petroleum depot easier, faster and more cost-effective.

Recommendations

With an increasing global demand for speed and efficiency in the workplace as a way of increasing productivity, there is a need for managers of petroleum depots to improve the cost-effectiveness of pipeline route selection procedures. The findings of this study are recommended for implementation in full scale as this will go a long way to furnish both researchers and professionals on the field with further insights in their bid to optimize petroleum depots management and products distribution.

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