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Optimizing Energy (Fuel/Oil) Wastages Due To Human Error Criticalities On Board Naval Ships

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***Abstract**: This research involves the analysis of fuel/oil wastages on board naval vessels. The approach was unique, as Delphi methods using experts in sea operations who are naval personnel formed the elicitation groups. MILP formulation using the maximum flow network algorithm was eventually developed from the results of the elicitation meetings. The model was solved using Lingo^{R}software. The result indicate that the optimum value returns more than 33% savings of fuel/oil wastages. Using this unique combination technique is novel in the solution of similar problems and optimizing resources for managers of seagoing navalvessels.*
***Keywords:** Delphi method, consensus group, sinks and source of flows, maximum flow through networks*

I. Introduction

Increased energy efficiency on board naval ships is paramount not only in cost reduction and for enhancing operational efficiency, but also in mitigating land and sea ecological damage due to carbon emissions and sea contamination. Efficient usage of energy affects its future availability by reducing its consumption, affects the economy of ship owners positively, and conserve land and sea ecology. Although research indicates that the potential for improving energy efficiency in shipping is evident (Johnson, Johansson, & Andersson, 2014), situations witha large potential for improvement exist without being realized by the managers and operators of ships. These situations are called *energy efficiency gaps*. Although these gaps have been attributed to barriers and failures in markets, institutions, and organizations, these are not the only factors in energy efficiency gaps. Other attributable factors include human energy behaviour, especially human behaviour in dealing with energy-related activities or energy content materials on board ships.

Energy behaviour has been extensively investigated in the literature. Recently, Lopesa, Antunes, and Martins (2012) indicated that energy-saving behaviours are often confused withhigh technology and cost-efficient solutions. However, these authors, having reviewed the literature on energy-saving behaviour, concluded that, although energy-saving behaviour is vast, it is essential to establish behavioural determinants in order to develop the best strategies and instruments to promote more efficient energy behaviour. For this reason, understanding how individuals make decisions about energy use is important and can also pose as a determinant, strategy, or even instrument. As such, human behaviour as an intervention between energy content material and energy usage by machine or equipment is essential. For example, on ships, research has shown that there exists greatpotential to increase energy efficiency through reduced speed at sea and enablingshorter port time duration (Johnson & Styhre, 2015). Although these decisions may not be at the discretion of ship operators, they form an important aspect of the energy-efficient decision-making process that needs to be considered. Research has also suggest two main roles in the decision-making process for the energy-efficient behaviour of ships operators. The first is to help explain behaviour on board and identify important behavioural drivers for energy-efficient activities. The second is to provide a framework for energy-efficient behaviour on board and the impact of these interventions (Wilson & Dowlatabadi, 2007). Thus,energy-efficient behaviour on board ships could have a two-pronged approach: on board and at the command or control position.

This paper reports on ongoing research that aims to investigateenergy-efficient behaviour on board naval ships. The focus of the paper is on handling fuel/oil energy programs on board naval ships. The approach is in pursuit of greater efficiency in the use of fuel/oil on board. The paper identifiespotential improvement in fuel/oil handling, usage, returns, and in other ship incidences using a combination of the Delphi method and Mixed Integer Linear Programming.

This unique approach to fuel/oil efficient use on board naval ships aims at reducing human errors in activities involving fuel/oil and influencing human behaviour towards energy-efficient actions. This approach uses naval seamen to suggest when, where, and how fuel/oil are wasted on board. Fuel/oil activities on naval vessels are hugely complex and shaped by many factors, largely individual and contextual. Due to these complexities in activities, individual or human-induced wastages are also many and shaped by many factors. Recent research indicates that human behaviour is as important as physical infrastructure in energy-efficient use (Lopesa et al., 2012). This means that proper consideration of human factors is a key ingredient of effective energy-efficient management. As human factors area broad field of human reliability engineering, some important issues, such as how human errors cause or contribute to inefficient energy management, have not been investigated in relation to fuel/oil use on board naval vessels. This paper contributes to the literature by investigating human errors in fuel/oil activities on board Nigerian naval ships.

Human error is an action or decision thatwas not intended and which involved a deviation of standards acceptable for that particular task or activity. Human errors almost always result in an undesirable outcome. This research is part of an ongoing studyon energy-efficient utilization on board Nigerian naval ships. This paper answers the following questions: What are the specific human errors that impact on fuel/oil activities on board naval ships? What practical ways can be used to identify, assess, and control these errors? How can these errors be optimised and eventually eliminated using proper energy-efficient behaviours?

The next section provides the literature review. Section 3 introduce the method used in this research. Section 4 discuss problematisation and conceptualisation of the problem.Sections5, 6, and 7 discuss problem formulation, discuss the results, and draw conclusions, respectively.

II. Literature Review

Human error is part of everyday work life. Although human errors are undesirable, they take the shape of human behaviour that can be considered unwanted, unacceptable, and often avoidable. Noroozi, Khakzad, Khan, MacKinnon, and Abbassi (2013) investigated human errors' influence on maintenance and post-maintenance activities on facilities in the process industry. Their study used scenarios in which human error probability was calculated for each activity using the Success Likelihood Index Method (SLIM) methodology to rank human errors. Fortheir part, Cacciabue (2004) developed a methodology called Human Error Risk Management for Engineering Systems,whichwas applied to different practical systems to study sources and the impact of human errors on the system studied.

Human errors can be classified into two categories—errors that are skilled-based and those that are by mistakes in operations (Dekker, 2000, pp. 35-51). Errors that are skill-based include those that are due to lapses and those that arise because of slips or failures in carrying out activities or the actions of a task. These kinds of errors are in action, such as picking up a wrong component or applying too much or too little strength in torqueing a bolt or a hose joint. This may also include performing an action too soon or too late. It is the type of error that also involves omitting a step or series of steps ina task. This type of skill-slip error could also be doing the right things on the wrong component or doing the wrong thing on the right component. It may also involve carrying out wrong checks on an item or doing the right check procedures on the wrong parts of the component. Put together, this research consider this kind of human errors as errors due to negligence.

Other errors include errors that occur due to mistakes in doing certain activities. For example, some authors report errors where we do the wrong thing, believing that it was the right thing (Bea, 1994). This error involves our mental processes, which we control in how we plan, assess information, make intentions, and judge consequences. This research work considers this type of error as an error due to human cognition.

The third type of errors considered here are those due to deliberate violations of procedures due to situational, routine, or other exceptional conditions (Noroozi et al., 2013). This type of error is often considered normal by operators, as breaking procedures has become the norm, or where breaking arule is due to pressure from the job. In certain circumstances, operators break a rule in order to solve a problem and in the process do not even consider what was done as procedure-breaking.

Research, particularly in medicine, has studiedthe above three types of errors and their impact on practice, design, and system operations. Sohn (2013) acknowledgedthat negligent and system errors are contributors to errors in medical practices. Bea (1994) indicatedthe application of human reliability technology on the development of criteria for ship structures. The author addressed a variety of sources of human error in the design of marine structures and concluded that human and organisationalerrors (HOEs) contribute significantlyto a lack of reliability in marine structures.

This work considers these three human errors and formulates mathematical programming using the network modelling approach to optimize fuel/oil wastages. Maximum flow through network principles was used in the formulation and the resulting Mixed Integer Linear Programming(MILP), and the problem was solved using Lingo^{R} 14 software. Maximum flow problem principles have been used in previous research as efficient algorithms in the solution of a number of optimisation problems. For example, Winston and Venkataraman (2003, pp. 420–425) optimised oil flow between cities, whereas Jain (2010) developed various algorithms for solving maximum flow problems. Other researchers used maximum flow problems to minimise an objective. Mughees, Al-Ahmad, and Naeem (2013) used maximum flow principles in the design and analysis of water/wastewater networks in order to minimize water usage in the petroleum industry. Also, Liberatore, Scaparra, and Daskin (2011) developed a model that optimally allocates defensive resources among facilities in order to minimise worse-case interdictions of product supply lines.

III. Network Models

Network models are a class of problems that have different demands and supply points, such as the transportation and assignment of problems. In the network problem, each supply point (or source point) hascapacity, and the demand points (or sink) also have a demand. Various models have been developed to solve network problems. Some of these models have been extensively discussed in Bazaraa, Jarvis, and Sherali (2010);Gen, Cheng, and Lin (2008); and Ahuja, Magnanti, and Orlin (2014).

In this paper, an approach has been proposed to optimise energy wastages on board naval ships through proper removal or minimization of wastages occurring due to human errors in handling, usage, returns, and the incidences of fuel/oil use on board. Human error is selected as the target source of wastages, and the various wastage points as determined by a group of expert (see the Methodssection) are used as sinks or wastages values. A mathematical program has been developed to optimise the problem, and an expert opinion was sought to solve the problem in line with the optimised solution outputs. There are foursolution results. The first step was taking the data provided by the experts. Then subsequent solutions were obtained from target achievement levels of 75%, 50%, and 25% of wastage reductions using the original opinion provided by the experts. The result has also shown the optimum wastages from each of the used target wastage sources.

3.1 The Optimization Method

For this paper, the maximum flow problem is the choice of optimisation problem adopted. The maximum flow problem is one of the two important network problems thataim to find a feasible flow through a single source, or a single-sink flow network (Ahuja et al., 2014). In some problems, as is the case in this work, it is necessary to distinguish among the items that flow into the network. This class of network problems, called multi-commodity network problems, are often more naturally encountered in everyday problems (Bazaraa et al., 2010). Multi-commodity network flows are a class of network problems in which the unit flowing along the networks must be distinguished. The problem considered in this work can be analysed as a multi-commodity network problem, as the target wastages in the network area (see figure below) are three distinguishable human error; each contributes in a certain proportion to wastages due to one or all of the activities/processes done to fuel/oil on board.

Network problem means that a network is analysed where a network is given and some analysis is performed on it. Further to just analysis, a synthesis is also required on the network;that is, we must construct an optimal network that satisfies certain specifications.

IV. Research Methods

In this work, structured elicitation methods as reported in (El-Ladan & Turan, 2012) comprised the following: single experts, consensus groups, and Delphi elicitations were followed in order to identify appropriate values for errors due to certain fuel/oil activities on board. At various sessions, experts were presented with available fuel/oil wastage points as obtained during the literature review. Also presented was a table of factors responsible for these wastages as per the literature. Experts were then asked to provide input as guided by the following review questions:

1. What human errors largely contribute to oil/fuel wastages on board naval ships?
2. How do these human errors contribute to oil/fuel wastages on board naval ships?
3. How can these human factors be classified and quantified?
4. In what ways can human factors be eliminated or utilised in order to improve fuel/oil use and hence overall energy efficiency on board?

The conduct of elicitation is guided by the theoretical assumptions and methodological procedures for Delphi forecasting (HELMER, 1994). Several authors (Mikaeil, Ozcelik, Yousefi, Ataei, & Hosseini, 2013; Rowe & Wright, n.d.) indicated that Delphi is appropriate for the development and assessment of criteria, ranking, and objectives when there is no available data. This point has made Delphi a method of choice in theanalysis of energy wastages that do not have data to refer to. Similarly, data gathered through Delphi have been shown to be valid for analysis in similar works (Klenk & Hickey, 2011). Besides its advantages, Vandeven and Delbecq (1974) compared its effectiveness to those of other methods and indicated its superiority over some other techniques.

4.1 Conduct of the Elicitation

Experts, sometimes called subject matter experts (SMEs), were carefully selected and were briefed as indicated in the preceding paragraphs. The SMEs were grouped in order of their known assigned responsibilitieson board. These includedthreeindependent groups of commissioned officers (junior), twosingle experts of the rank of senior command positions (senior officers) who formeda consensus group, and two other groups consisting of naval technicians and seamen. In this study, the following procedures were followed:

i. Each Delphi group was allowed to and guidedin choosing a facilitator. Experts were subsequently briefed and presented with the various methods of fuel/oil energy activities on board according to the literature.
ii. With the list of activities that could result in wastages (both from the literature and the experiences of the experts), the groups were asked to rank wastages that are due to human error in those activities and what type of error they would be. The figure below provides a summary of the results of the group discussions.
iii. With the outcome of the groups, some of the identified sources of wastages were reduced to questionnaire form and aLikert-type scale. The questionnaires were distributed to the experts for onward distribution to other respondents in order to get the perceptions of others, particularly on the errors identified, rank (or score), and the activities including all other aspects identified by the groups. The experts had questionnaires for a period of 15 days.
iv. Questionnaire results and analyses provide a score of ratings errors and activities in terms of importance to which each of the error or activities independently affects positively or negatively on fuel/oil wastages on board.
v. TheSMEs were then assembled to discuss the results obtained, and after several rounds of discussions, debate, changes, improvement, etc.,the experts agreed on the ratings of each of the errors and each of the activities.
vi. Eventually, the scores agreed upon were then combined to determine the probabilities of errors occurring and also the value/quantity of wastage for each of the activities and sub-activities under it.
vii. These were then used as frequencies of occurrences in the subsequent analyses.
viii. The second group (senior officers), by virtue of their ranks and length of service (25 years and 29 years in service), were made the consensus group for elicitation purposes. The consensus group's elicitations were similar to that of the Delph method but without a facilitator. At this stage, three process were aimed at—eventually focusing on the whole solution as provided in the preceding stages, prototyping experiences, and discussion in order to understand further things that are necessary in the research. As such, expertscontributedin the deliberations, and a final judgement was reached by consensus without facilitation, with the researcher available to provide further information asrequired.
ix. The consensus groups were used as the final arbiter in the development of human error probabilities and the eventual activities that were subjected to the human errors.

4.2 Results of the Delphi

The SMEs identified activities that are impacted by human errors on board naval ships. The figure below returns a summary of such activities. It should be noted that each of the four identified activities have sub-activities that may not necessarily be common to all naval ships. However, the consensus is that the fourmajor activities are common and essential to all ships, and will thus be discussed below.

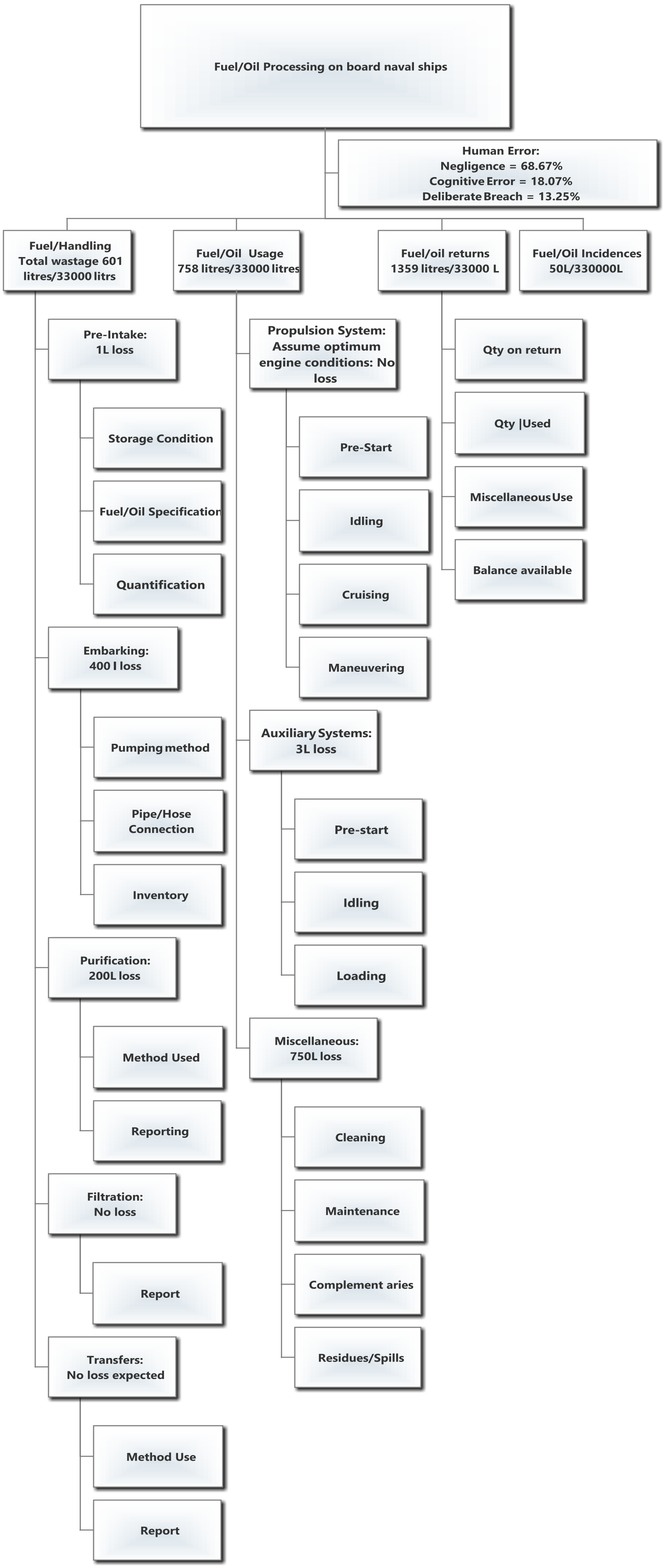
a. Fuel/oil handling: This spans all activities between receivingfuel/oil, storage, and consumption. During handling, the fuel/oil must be transferred (such as between storage and tanks), filtered, and purified in order to meet engine usage specifications. This can be a complex and often monotonous process leading to errors, including human errors. Poor handling can lead to engine breakdown, contamination of miscellaneous facilities on board, and ecological damage due to fuel/oil spills.
b. Fuel/oil usage: The rising cost of fuel has brought much attention tothe use of fuel on board ships generally and naval ships in particular. One reason for that is that fuel/oil that is used in ships must undergo pre-use treatments, including oiling, to ensure correct atomisation upon injection. All these pre-injection procedures are sources of wastages and must be handled properly. Processing may lead to leakages and other wastages that are difficult to account for.
c. Although the specification of each fuel/oil unit to use is contained in the ship's instructions, often some of these fuel/oil units may not be good to use and as such haveto be returned. Although returns are cost-additive, wastages of fuel/oil due to returns add extra costs to ship managers and must be eliminated as much as possible. Normally, unused materials, including fuel, are stored in a dockyard on board;storage also contributes to wastages.
d. Incidences such as stormwater drainages, accidental spills, undetected leaks, heating/cooling activities, and cleaning up of facilities and equipment are some incidences that result in fuel/oil wastages on board naval ships. Others include waste recovery and disposal of waste off board.

As discussed above, the listed activities are the major activities involved in fuel/oil wastages, and each of these have several sub-activities with accompanied sub-sub-activities or elements. Figure 1 summarises these activities, sub-activities, and elements within each of the sub-activities, as discussed by the Delphi elicitation groups.

Based on the findings, the table below provides the agreed-upon figures of, first, the sink as fourfuel/oil activities and, second, the sources as threehuman errors of wastages. The figure that follows the table shows all the sinks and the suggested wastages at the sink. Figure 2 also shows the relationship between sources and sinks of wastages. Using the relationships depicted and the figures suggested by the Delphi groups, a mathematical programming technique was formulated and solved using Lindo 14.0.

Further to the output shown, three other models were run. The aim was to constrain estimated value wastages to certain %s of the original group estimate. The table below indicates the output from the chosen values of 75%, 50%, and 25%.

Sink	Max Tank Load (lts)	Max % Loss	Loss Due to Activities (lts)
Fuel/Oil Handling	33,000	0.018	601
Fuel/Oil Usage	32,399	0.023	758
Fuel/Oil Returns	31,641	0.043	1,359
Fuel/Oil Incidences	30,282	0.0016	50
	Sources of human error	Proportion	Values (Ltr.)
	Negligence	0.687	1,901.62
	Cognitive Error	0.181	500.17
	Breach of procedure	0.1325	366.76
Table 1: aggregate results			


Fuel/Oil Processing on board naval ships
Human Error:
Negligence = 68.67%
Cognitive Error = 18.07%
Deliberate Breach = 13.25%
Fuel/Handling Total wastage 601 litres/33000 litrs
Fuel/Oil Usage 758 litres/33000 litres
Fuel/oil returns 1359 litres/33000 L
Fuel/Oil Incidences 50L/330000L
Pre-Intake: 1L loss
Storage Condition
Fuel/Oil Specification
Quantification
Embarking: 400 l loss
Pumping method
Pipe/Hose Connection
Inventory
Purification: 200L loss
Method Used
Reporting
Filtration: No loss
Report
Transfers: No loss expected
Method Use
Report
Propulsion System: Assume optimum engine conditions: No loss
Pre-Start
Idling
Cruising
Maneuvering
Auxiliary Systems: 3L loss
Pre-start
Idling
Loading
Miscellaneous: 750L loss
Cleaning
Maintenance
Complement aries
Residues/Spills
Qty on return
Qty |Used
Miscellaneous Use
Balance available

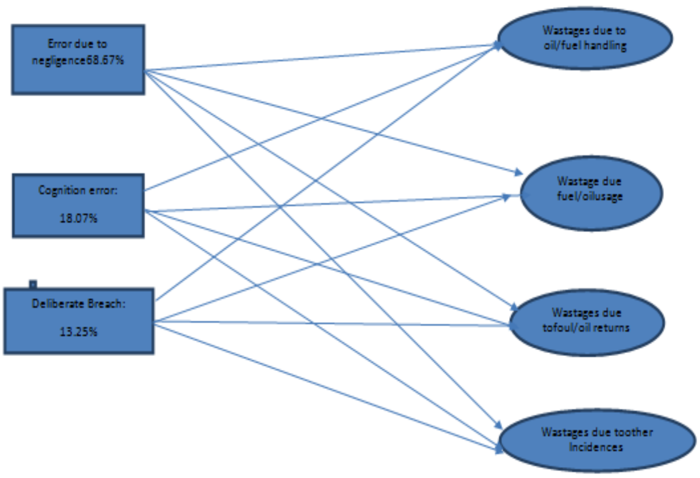


*Figure 2.*Human errorsand fuel wastages network distribution.

Problem Formulation

To formulate the problem, formal description of the maximal flow problem as discussed in Bazaraa et al. (2010, pp. 608–609) is required:

a. With m nodes, sources of materials.
b. Having n arcs through which a commodity will flow.
c. An associated lower bound on flow to arc (i, j) of $l_{ij} = 0$.
d. An upper bound of flow u_{ij}.
e. Assume that the u_{ij} - values are finite integers.
f. Assume also that there is no cost involved in the maximal flow problem.

Find the maximum amount of flow through the network from node 1 to node m.

If *f* is the amount of flow in the network from node 1 to node m, then the maximal flow problem may be mathematically presented as:

maximize *f*

Subject to

$\sum_{j=1}^{m} x_{ij} - \sum_{k=1}^{m} x_{kj} = (f \text{ (if i = 1)}, 0 \text{ (if i NE 1 or m)}, - f \text{ (if i = m)})$

$x_{ij} <= u_{ij}$, i, j = 1,....., m

$x_{ij} >= 0$, i, j = 1, ..., m

As the sums and inequalities have taken over existing arcs in the network, this formulation is referred to *node-arc formulation*for the maximal flow problem. The above is a general way of solving node-arc maximal flow problems.

To solve the problem described in this paper, consider the directed graph (Figure 2) such as the one presented in the figure above. This graph can be assumed to represent a flow network. In this problem, human error is modelled as a material (or cause of a material flow) through a system from a source, one of the known errors where the material is produced, to a sink, one or more of the activities causing wastages where it is consumed. The source productionis assumed to be occurring at asteady rate (for example, human error due to negligence at arate of 68.67%), and the sink consumes the material at the same rate (constituting 68.67% of the wastages in handling, for example). So in this formulation, it assumed that there is a maximum equals to 2,768 litres, and, using this maximum value, we formulate the problem as a minimization of this value. Each of the sources contributes to this maximum value, and so also each of the paths.

For example, fuel/oil handling contributes 601 litres of the total wastages,which is 0.018% of the total 33,000 litres of fuel. The arc from human error due to negligence to fuel handling activity is directed and, according to the maximal flow algorithm, can theoretically be optimised. So also are all the other arcs in the figure above.The Lingo output for the problem returns a value of wastages that is more than 33% less than the original estimate.

V. Results And Discussion

Consider the output below. The original loss was 2,768 litres of fuel/oil per 33,000 litres. The output of the first run indicates that 1,835.343 litres of fuel/33,000 litres was eventuallylost, fora reduction of 33.7%. To attain this the output, indicate that only 8 litres of fuel should be lost per 33,000 litres due to negligence while handling fuel. Similarly, only 25 litres should be allowed to be lost due to negligence while fuel is being used. The largest amount of fuel loss is due to cognitive error.

The table below also provides outputs for the other threeruns of the model. From the table, it is clear that maximum savings of fuel wastage could be done using the arcs or directed arrows of the model run. For example, if it is desired to reduce wastages by 50%, ship managers may discuss the possibility, including taking into accountavailable resources (both equipment and personnel) and targets to reduce the highest flow or eliminate the least. The first run indicates that 500 litres arelost due to error in cognition while handling fuel/oil. The task here is to study which of the sub-activities in handling cause such large amounts of wastage. Eliminating such targeted activities by either bypassing it or training personnel to handle it well could be a solution. On the other hand, all the output due to negligence could be carefully eliminated and others systematically reduced. It should be noted that it could be difficult to totally eliminate errors, and as such, targeting the reduction may provide a better alternative.

Model Output	Feasible Solution	Wastage Due	Wastage sink	Value	Reduction Reported
1.	1835	Negligence	Handling	8.005962	
		Negligence	Usage	25.37700	
		Negligence	Returns	32.34423	
		Negligence	Incidences	0.000000	
		Cognition	Handling	500.1700	
		Cognition	Usage	0.000000	
		Cognition	Returns	0.00000	
		Cognition	Incidences	0.000000	
		Breach	Handling	92.82404	
		Breach	Usage	0.00000	
		Breach	Returns	273.3322	
		Breach	Incidences	0.6037736	
2. 25 % Cut	1309.502	Negligence	Handling	54.77814	
		Negligence	Usage	25.37700	
		Negligence	Returns	36.14571	
		Negligence	Incidences	0.000000	
		Cognition	Handling	375.1275	
		Cognition	Usage	0.000000	
		Cognition	Returns	0.000000	
		Cognition	Incidences	0.000000	
		Breach	Handling	20.84436	
		Breach	Usage	0.000000	
		Breach	Returns	253.0000	
		Breach	Incidences	0.6037736	
3. 50 % Cut	783.6605	Negligence	Handling	106.4184	
		Negligence	Usage	25.37700	
		Negligence	Returns	35.07908	
		Negligence	Incidences	0.000000	
		Cognition	Handling	194.0816	
		Cognition	Usage	0.000000	
		Cognition	Returns	56.00343	
		Cognition	Incidences	0.000000	
		Breach	Handling	0.000000	
		Breach	Usage	0.000000	
		Breach	Returns	182.7762	
		Breach	Incidences	0.6037736	
4. 75 % Cut	265.0366	Negligence	Handling	150.2500	
		Negligence	Usage	25.37700	
		Negligence	Returns	34.60392	
		Negligence	Incidences	0.000000	
		Cognition	Handling	0.000000	
		Cognition	Usage	0.000000	
		Cognition	Returns	125.0425	
		Cognition	Incidences	0.000000	
		Breach	Handling	0.000000	
		Breach	Usage	0.000000	
		Breach	Returns	91.08623	
		Breach	Incidences	0.603773	

Table 2: Model results

VI. Conclusion andRecommendation

The result of this stage of the research uses aunique technique based on a combination of Delphi elicitation and maximumflow on a network approach; it has shown a very good percentage of reduction of wastages ofmore than 33%. The best possible wastage networking was obtained using mathematical programming. This best result was further improved when the targeted reduction was made the basis as indicated in Table 2.

In the future, research will consider multiple layers of wastages and will optimise the network in order to locate the sink from the root. As shown in Figure 1, experts indicate that there are fivesources of wastages in fuel/oil handling alone. This could provide another layer of analysis, and as subsequent elements are identified by SEMs, third and fourth layers could be developed. Another aspect of this research that is worth further consideration is taking the entire energy system on board to optimise. Other approaches of ranking and weighing sources and sinks of wastages could also be explored. ANP/AHP techniques could be used to rank or weigh the errors, and multiple error sources could be consideredas well.

6.1 Relevance to Theory and Practice

The theoretical relevance of this work is in the unique approach of combining two methodologies to determine the optimum value of oil/fuel wastages. The methodologies that have been fully discussed include the qualitative Delphi methodology in the development and agreement of human error probabilities due to what was referred to as human error criticalities. Although there may be other error terms, the elicitation groups agreed that the three determined are the most critical. The quantitative evaluation of the optimum values of wastages using MILP utilises the values of all the sinks and sources as determined by the groups.The practical relevance is that using a combination of methodologies derived from the experiences of operators or people directly involved in the issues provides clear relevance.

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