Goal Programming Approach for Waterway Transportation System

Akinlo Olorunju Mogbojuri and Oludolapo Akanni Olanrewaju
Department of Industrial Engineering
Durban University of Technology
Durban, South Africa.
akinlo.mogbojuri@gmail.com; oludolapoo@dut.ac.za

Olatunde Joseph Oloyede
Department of Mechanical Engineering
University of Lagos, Nigeria.
olatundeoloyede41@yahoo.com

Abstract

The motion of humans and commodities from one scene to another using various vehicles and facilities is known as transit. It's also critical to economic growth and people's health because it allows them to work, go to school, make purchases for food and other necessities, and participate in all of the activities that contribute to human life. Using the waterways transportation system has the benefits of reducing road traffic congestion, provides a significant source of income to the public treasury, brings multiple employment options for employees, minimal operational costs, free natural transport network, marking development to towns through the connection with canals, air pollution and savings cost. In this study, we present a goal programming (GP) model to optimize waterway transportation in a location with road congestion to enhance the transportation system. The goal programming approach is applied from the data of the Lagos State Waterways Authority (LASWA) in Nigeria. The goal programming method is effective and the findings indicate the potential to increase the number of commuters using the waterway transportation from 7,640 to 10,026. Also indicated in the findings were the reduction of fares as potential cost reductions by ₦200.00, reduce travel time by 4 minutes, and increased vessel numbers of Ebute Ero – Ikorodu (x_2) to 528/540. The findings and approach are generalized for waterway transportation optimization.

Keywords
Goal Programming, Optimization, Traffic congestion, Transportation and Waterway.

1. Introduction
Transportation is the movement of individuals and goods from one location to the other using different vehicles and facilities. Transportation is critical to economic growth and people's health because it allows them to work, go to school, make purchases for food and other necessities, and participate in all the activities that contribute to human life. More mobility enables people to achieve their personal goals by improving access to more destinations, but it comes at a higher cost, both individually and socially (David et al. 2009). There are numerous types of transportation for both goods and people, which are divided into four major categories: train, road, water, and air (Akinbamiyo et al. 2016).

Waterway transportation is extremely important in the transfer of humans, commodities, and values from one riverine location to another all over the world (Ibama et al. 2015). Because transportation fosters profitable development and employ generation, it must be justifiable in the face of current problems. Waterway transportation is both more environmentally friendly and less expensive than other modes of transportation (apt to providence). Furthermore, because a sole ship can return over 100 freighters, expand use of the waterway system is probable to lessen road gridlock and accident rates (Buchem et al. 2022).

Waterway transit is the ancient means of movement and is critical to the growth of any country. It is a means of transit for both agrarian and city residents, especially those who live near riverine and inshore waterways. Despite the socioeconomic and environmental benefits of waterway transportation, this mode of transportation is underutilized (Bayode and Ipingbemi 2016). Waterway transportation is the cheapest and safest means of transportation, and it can be depended on for enjoyable and peaceful trips when high-quality services are offered (Bassey and EkpenyongNsa 2018). Waterway transportation is associated with inland waterways, coastal waters, and the deep sea. Rivers, lakes, coastal creeks, lagoons, and canals are examples of inland waterways found within a state's territorial boundaries (Akinbamiyo et al. 2016).

Waterways are important in many developing countries' transportation systems because they are less expensive and more accessible than other options, resulting in a high demand for product and passenger transportation (Mohaimenuzzaman et al. 2016). Because of its significant movement volume per automobile measurement, suitability for a wide range of consignment, from dry and fluid mass freight in huge capacities to general haul, yard goods, and vessels, and, as a result, cheap transportation cost and effusion per ton kilometer, inland waterway transportation (IWT) is a powerful mode of transportation. In continental traffic, the most cost-effective mode of transportation is the inland waterway vessel. Furthermore, IWT not only provides a high level of safety for the transport of hazardous products, but it also subscribe to modal shifts and road and highway decongestion (Felde et al. 2022). According to Solomon et al. (2021), the movement of a vessel, such as a barge, river ship, over a perspiration, such as a lagoon, stream, or channel, is known as inland water transport (IWT). For both developed and developing countries, IWT has long been regarded as an economical, fuel-efficient, and low-cost mode of transportation. When compared to corresponding volumes of movement by road, rail, or air, it is thought to be more efficient, and environmental pollution is reduced. In any socioeconomic system, inland waterway transport is an unavoidable enabler of profitable, societal, governmental, and long-term growth. Adhikari et al. (2014) opined that the ability of inland waterways to efficiently transport large volumes of bulk commodities over long distances is one of their primary benefits. It is an important part of commerce, providing a cost-effective and alternative means of transporting goods. Using an inland waterway in an intermodal transportation network reduces road traffic congestion and thus pollution, while also lowering overall transportation costs.

1.1 Objectives

This study is focused on how to optimize waterway transportation in a location with road congestion of undeveloped road traffic system to enhance the overall transportation, using goal programming model to priorities the multi-objective problems.

2. Literature Review

Several studies have been conducted concerning waterway transportation system challenges and prospects. (Rohács and Simongáti 2007) investigated the position of inland waterway steersman ship in the development of a maintainable transportation network and presented reasons why it can improve sustainability. Smith et al. (2009) investigated the prospective accomplishment of a waterway resonator under various arrangement establishment and framework exchange using optimizing approaches, computer simulation, and expert opinion. The integrated approach yielded useful information for developing decision-making strategies for the inland waterway transportation system. Using Arena software, a discrete event simulation model was developed by Adhikari et al. (2014) to estimate performance measures such as lock usage and barge waiting time of the Ohio River's inland waterway transportation system. They assessed the current capacity level of the Ohio River waterway transportation system, as well as its feasibility in meeting future barge traffic demand. Zhu et al. (2015) used a Bayesian network approach for correlation coefficient analysis between various environmental characteristics and associated consequences to identify the safety critical factors (SCFs) of an inland waterway transportation system (IWTS). To improve navigational safety in complex environmental conditions, risk control options (RCOs) were proposed.

Akinbamiyo et al. (2016) examined the difficulties encountered by Lagos State's inland water-based transportation system. Their conclusions were criticized for the existence of water hyacinths, inadequate safety precautions, and a lack of proper funding and investment in inland waterways transportation. They advocated a unified control approach combining mechanical and biological eradication of aquatic plants for better river movement, as well as necessary funds.

Mohaimenuzzaman et al. (2016) proposed ways for developing countries to improve protection in waterway transportation networks formed on the Internet of Things (IoT). Their Intelligent Transportation System (ITS) concept can be used to create such a process; meanwhile, problems with ITS and IoT are revealing a novel approach to designing it. The scheme developed makes the system intelligent and secure for users. Wu et al. (2016) applied automatic identification system (AIS) data to investigate inland navigation in the Sabine-Neches Waterway in Southeast Texas. The study aided scholars and inland authority bureau in well understanding the navigation threat in the Sabine-Neches Waterway. Zhang et al. (2016) developed a Fuzzy Rule-Based Evidential Reasoning (FRBER) algorithm to evaluate the navigational threat of an inland waterway transportation system (IWTS). The approach could be used to model IWTS behaviors in other parts of the world, such as America and Europe, to improve inland waterway safety. Zhang et al. (2017) showed a possibility for enhancing the waterway transportation system, such as a natural event or unscheduled maintenance that may block an inland waterway and cause transportation disruption. They also evaluated the wider economic and societal consequences of the disruption. The closure of the inland canal system can be a major issue for shippers and other stakeholders involved in barge transportation. They created a framework for making decisions in the face of uncertainty when an inland waterway is disrupted. Oztanriseven and Nachtmann (2017) established a simulation method for estimating the potential profitable impact of inshore waterway disturbance reaction. The proposed technique was used to various research territories in order to quantify the profitable significance of other accessible water systems, which can improve the effectiveness of governments fund budgeting while also allowing organization partners to improve their willingness and potentially lower financial debts. Liang et al. (2019) proposed an integrated Fuzzy Analytical Hierarchy Process and Expert System to rank vessels in the upper Yangtze River's controlled waterways and created excellent traffic directions for each boat to guarantee marine security and congestion effectiveness. The proffered method can be applied to other strait one-way constricted waterways, providing perception into ship congestion in port, shoreside, and deep sea regions. Oztanriseven and Nachtmann (2020) developed a maritime transportation simulator (MarTranS) by integrating agent-based modeling, discrete event simulation, system dynamics, and multiregional input-output analysis to better understand the correlations among IWT network elements and their financial effects. The MarTranS can be applied to other segments or areas of the IWT system, as well as to assist maritime transportation partners in allocating asset allocations and increasing the financial profits of waterway transportation systems. Roso et al. (2020) used the Netherlands as a benchmark to identify the drivers and barriers to IWT in Sweden. The main drivers for IWT, according to the study, are gridlock comfort, price moderation, and reduced climate effect. Moreover, the blockade are the stagnant of growth, big expenditure prices, and bad hinterland affinity. Chen et al. (2020) examined the viability of using cooperative multi-vessel systems (CMVSs) to enhance transportation security and effectiveness in urban waterway structures. They proposed a scheme for vessel train formation (VTF) and cooperative waterway intersection scheduling (CWIS). Cooperative multi-vessel systems (CMVSs) help to reduce the total travel time and makespan. Solomon et al. (2021) used questionnaires, cross-examines, and open-ended examinations to study the managerial, retails, strategies, and scientific hinderances of Ghana's Inland Waterway Transportation (IWT) system. The study mentioned some advantages like the lowest approach of transportation, secure transit with a lower mishap account, and job establishment. Wang and Yuen (2022) examined the resilience of waterway transportation systems (WTSs). To quantify WTS resilience, they developed a discrete-event simulation model. The developed model can be used to improve system resilience in the future, allowing more risk management plans to be tested. Buchem et al. (2022) used a mathematical model called dynamic programming to optimize speed in IWT in area of unpredictability. The study reduced fuel consumption while demonstrating a plain exchange among the effectiveness and clarity of the guidelines under consideration.

The majority of studies have focused on the safety, risk, velocity, environmental, barrier, challenges, and financial effects of the IWT, while there is little attention on optimizing waterway transportation to reduce road congestion.

3. Methodology

3.1 Goal Programming Model

It is one of the mathematical programming models that provides a solution to a multi-goal optimization problem. The decision maker must utilize the goal programming model to establish an absolute priority order among the goals and to assign a target value to each of the goals (Chandra 2006). It is a method for assigning excellent worth to a group of variables when there are many competitive goals and a hierarchy of priorities exists between the goals. Goal programming sequentially addresses multidimensional goals (i.e., the main priority goal is completed first, followed by the next top priority, and so on (Tripathy and Biswal 2007).

Goal programming is an effective decision-making strategy that design to minimize the deviation among goal achievement and aspiration levels. It is the often applied multiple objective approach in management science due to its essentials resilience in dealing with managerial situations involving multiple discrepancy goals and insufficient or inexplicit insight (Azmi and Tamiz 2010). For problems with conflicting objective functions, goal programming is more beneficial (Hussain and Kim 2020). The Goal Programming model has two sub-models: the lexicographic (pre-emptive priority) goal programming model and the weighted goal programming model. The priority assigned to a goal determines the order of the pre-emptive priority elements. Pre-emptive GP is used when the desired goals have a clear priority ranking (Kumar 2019).

Model Formulation:
Thus, a proposed pre-emptive goal programming model is formulated as follows:

$$M\text{ in } Z=\sum_{i=1}^{m}\sum_{j=1}^{n} p_i(d_i^+ + d_i^-);\ i=1,2,3....m \tag{1}$$

Subject to

$$\sum_{j=1}^{n} a_{i,j}x_j - d_i^+ + d_i^- = \ \mathrm{G}_i\ ;\ \mathrm{j}=1,2,3,...n \tag{2}$$

$$x_j, d_i^+, d_i^- \geq 0 \tag{3}$$

x_i = 0 or 1

The objective function, denoted by (1), is the sum of all deviational variables. Equation (2) is the goal constraint function, also referred to as the linear constraint function, and (3) is the selection with binary variables and deviational variables that equal to or exceed zero.

P_i = Priority
m = numeral of goals
n = total numeral of decision variables.
z = objective function is defined as the amount of all deviational variables.
x_j = the *jth* set of decision variables
$a_{i,j}$ = the *jth* decision variable's coefficient in the *ith* goal.
d_i^+, d_i^- = positive and negative deviations i.e., overachievement and underachievement variables.
G_i is the aspiration level or goal associated with the objective *i* (Hamurcu et al. 2017 and Kumar 2019).

3.2 Case study analysis

The Lagos State Waterway transportation system in Nigeria was used as an account to exhibit the proficiency and viability of our model, as shown in Figures 1 and 2, as well as table 1.
Lagos state map were presented in Figure 1 and figure 2 showed the LSWA terminals and jetties across the state, while table 1 also shown Boat Terminal Routes.
Due to population growth and rapid globalization, Lagos State has emerged as Nigeria's commercial hub, according to (Mogaji 2020). Lagos, Africa's greatly populated metropolis, has the glowing inhabitant's quantity in Nigeria, with an approximated of over twenty million mankind spread beyond 3577 square kilometers. Railways, rivers, and road transit aid Lagos' transit demands; meanwhile, the infrastructures in lay down are insufficient, unmanaged, and outdated, and do not efficiently serve the transit needs of its population. For decades, traffic congestion has been a major issue in Lagos. Every day, an estimated 8 million people use public transportation to get to work on Lagos' 9,100 roads and expressways and commuters in the state face the effects of traffic congestion. The water-controlled state's total area is 779.56 square kilometers, accounting for 21.79% of the state land mass, emphasizing the need to explore the waterways transportation system (Budget- Economic Intelligence Unit of the Lagos state Ministry of Economic Planning 2013) . In the study of Adejare et al. (2011), Lagoons and creeks cover a sizable portion of the state's land area. The Lighthouse creek, Ologe lagoon, and the major waterway central to Badagry are all located west of the lagoon (southwest of the lagoon) and (Port Novo and Cotonou). Five Cowries Creek is another creek that connects the southern part of the major Lagos Creek to the Atlantic via Victoria Island. The lagoon's northern edge is spring by the Ikorodu local port, which steers to Epe. There are also numerous bays from the Ogun River, Majidun River, and Agboyi Creek in that area. The Lagos lagoon has a sub-lagoon to the east of the jetty, and the bar beach among the Atlantic Ocean and the creek is known as the Kuramo waters.

According to World-Bank (2016) Lagos State Waterways Authority (LASWA) was set up in 2008. The Waterway is managed, to improve and enhance navigation opportunities by the LASWA, but the ply of ferries and boats is not widely accepted because humans believe it is unsafe and does not serve most destinations. LASWA monitors private operators to ensure they comply with waterway regulations, but it has limited capacity and funds. Despite progress in the availability of lifejackets for passengers, there have been reports of avoidable accidents.

According to The-NEWS (2020), Lagos State Emergency Management Agency (LASEMA) Marine Rescue Unit, under the Lagos State Government has purchased over 5,000 drones and has already connected them to its Command Control Centre with CCTV equipment and mobile CCTV technology to improve security in the state. They also purchased 10 additional boats to aid in rescue operations, medical boats, and citizen protection in the state, with drones to monitor the waterways. Their shore base in Lekki serves as the headquarters of LASEMA's Marine Rescue Unit, which operates from four jetties in Lekki, Ikorodu, Ilaje-Bariga, and Ijegun-Egba. Meanwhile, there are 26 jetties and five terminals in Lagos State, with over 100 operators, 90% of which are private, and 10% of which are government-owned. The renovations to the jetty and the repairs, expansions, and restoration of existing terminal facilities have increased the number of passengers using the services (World-Bank 2016). Therefore, to explore the waterway transportation system, a goal programming model will priorities the number of commuters, number of vessels or boats, cost of transportation and minimum travel time for overall transportation and decongest road traffic.

Figure1. Lagos State Map

4. Data Collection

The following data were collected from each route: number of daily commuters, number of vessels or ferries **(530)**, the total number of boats operational, time taken to convey commuters, and fares were collected at the Lagos State Waterways Authority (LSWA) office were shown in Table 1.

Table1. Boat Terminal Routes.

Routes (x)	Daily Commuters	No of Ferries	Time (min)	Fares (₦)
CMS – Ikorodu (x_1)	2000	60	25	1,200
Ebute Ero –Ikorodu (x_2)	2000	60	25	1,200
Ebute Ero – Ijede (x_3)	200	2	25	1,200
Ebute Ero –Ibeshe (x_4)	20	1	20	1,200
Ikorodu – Falomo (x_5)	3060	60	25	1,200
Ikorodu – Apapa (x_6)	200	10	30	1,200
Ikoyi – Ijede (x_7)	100	4	25	1,200
Ikoyi – Ibeshe (x_8)	40	2	20	1,000
Ikoyi – Bayeku (x_9)	20	1	30	1,000

Source. Lagos State Waterways Authority (LSWA)

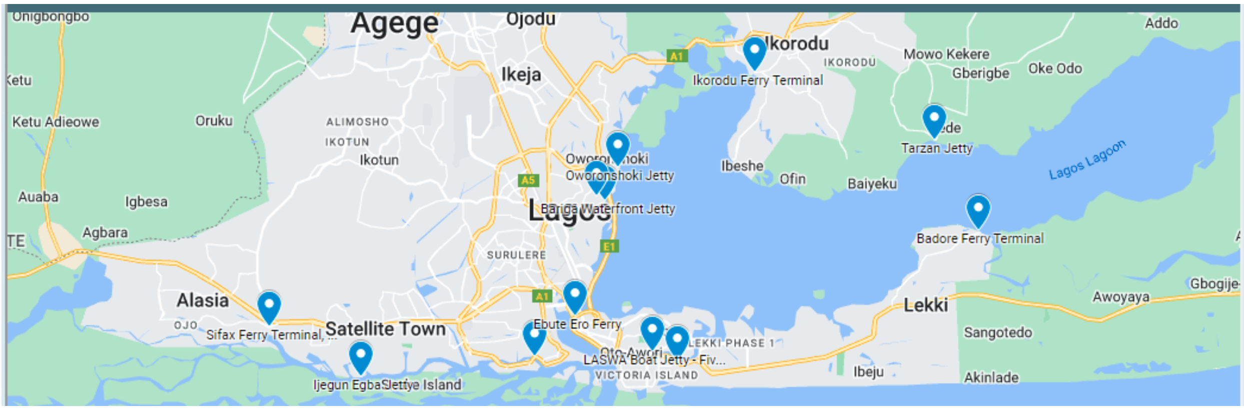

Figure 2. LSWA Terminals and Jetties

5.0 Results and Discussion

5.1 Model Application

A concept of pre-emptive priority goal programming is used.
The priorities are:
1: Maximize the number of commuters

2: Maximize the number of vessels or boats

3: Minimize the cost of transportation

4: Providing minimum travel time

From Table **1**, the model used in this study were:

Minimize Z= $P_1(d_1^-), P_2(d_2^-), P_3(d_3^+), P_4(d_4^-)$ (4)

Minimize Z= $(d_1^-)+(d_2^-)+(d_3^+)+(d_4^-)$

Subject to:

Priority 1: Maximize the number of commuters

$$2000x_1+2000x_2+200x_3+20x_4+3060x_5+200x_6+100x_7+40x_8+20x_9+d_1^- - d_1^+ = 7,640$$

Priority 2: Maximize the number of Vessels or boats

$$60x_1+60x_2+2x_3+x_4+60x_5+10x_6+4x_7+2x_8+x_9+d_2^- - d_2^+ = 530$$

Priority 3: Minimize the cost of transportation

$$1200x_1+1200x_2+1200x_3+1200x_4+1200x_5+1200x_6+1200x_7+1000x_8+1000x_9+d_3^- - d_3^+ = 10,400$$

Priority 4: Providing minimum travel time

$$25x_1+25x_2+25x_3+20x_4+25x_5+30x_6+25x_7+20x_8+30x_9+d_4^- - d_4^+ = 225$$

$$X_j = 0 or 1; V_j = 1,2,3,4,5,6,7,8,9$$

5.2 Numerical Results

Table 2. Model Result

Routes (x)	Value	Deviations (d_i^+, d_i^-)	Value
CMS – Ikorodu (x_1)	0.0	d_1^-	0.0
Ebute Ero –Ikorodu (x_2)	8.8	d_1^+	10026.67
Ebute Ero – Ijede (x_3)	0.0	d_2^-	0.0
Ebute Ero –Ibeshe (x_4)	0.0	d_2^+	0.0
Ikorodu – Falomo (x_5)	0.0	d_3^-	0.0
Ikorodu – Apapa (x_6)	0.0	d_3^+	200.00
Ikoyi – Ijede (x_7)	0.0	d_4^-	4.1666
Ikoyi – Ibeshe (x_8)	0.0	d_4^+	0.0
Ikoyi – Bayeku (x_9)	0.0		

Multi-goal optimization is utilized to establish priorities through the pre-emptive priority model and was solved using the LINGO 18.0 Software package. The result in Table 2, shows that the total passengers or commuters plying the routes can be increased to 10,027 instead of the current commuters of 7,640 and with these, the fare of each route can be reduced by ₦200.00, likewise the time taken can be reduced by 4 minutes. Hence, there is a prospect for government or private operators on the Ebute Ero – Ikorodu route (x_2) to utilize the number of vessels from 60 to 528 or fully utilize to 540. The study indicates the potential to increase the number of commuters, cost reductions, travel time reduction, and increasing vessel numbers. The developed waterway transportation system has the benefits of very low operating and maintenance expenses than rail and road transport, environmentally friendly, lower carbon emissions in minimizing pollution, ability to move beyond a long way interspaces, provides a significant source of income to the public treasury, brings multiple employment options for employees, free natural transport network, marking development to towns through the connection with canals and savings cost. The study contributes to optimizing underdeveloped road traffic systems, giving inland waterway transportation system prospects to invest more through collaboration with public-private partnership (PPP) like other modes of transportation. It promotes a long-term developmental agenda for waterway transportation system. The proposed model could be expanded to various research for optimizing inland waterways and improving transportation infrastructure.

6. Conclusion

The goal programming model was applied in this study to optimize and improve the waterway transportation system. The problem was formulated mathematically and solved using a software package called Lingo 18.0 which helps to increase the daily number of passengers or commuters and improves the overall transportation system. Thus, the number of commuters can increase from 7,640 to 10,027 daily, with the fare reduced to attract more passengers. Hence, Ikorodu's axis needs special attention to be fully utilized. The government can expand or increase other routes to accommodate more passengers in the state. It will improve any nation or region's economy.
Our approach can improve with an integrated model and be applied to vessel operations or scheduling, terminal or jetty selection, port handling, and to other modes of transportation. A meta-heuristic should be considered for further study. The implementation of the approach could be a way of conveying domestic freight through a waterway transportation system.

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Biographies

Akinlo Olorunju Mogbojuri is a Doctoral student in the Industrial Engineering department at the Durban University of Technology, South Africa. Mr. Mogbojuri received his Bachelor's and master's degrees in Industrial Engineering from the University of Ibadan, Nigeria. His area of interest focuses on operations management, project management, operations research, optimization, inventory management, and transportation. His research id includes https://orcid.org/0000-0002-1615-0842. He also has relevant experience in research and community services.

Oludolapo Akanni Olanrewaju He is the head of the department of Industrial Engineering, Durban University of Technology, Durban, South Africa. He earned his BSc Honours in Electrical Electronics Engineering and MSc in Industrial Engineering from the University of Ibadan, Nigeria, and his Doctorate in Industrial Engineering from the Tshwane University of Technology, South Africa. He has over 80 publications, is an associate member of the Southern African Institute of Industrial Engineering (SAIIE) and NRF rated researcher in South Africa. His research id includes https://orcid.org/0000-0002-3099-9295 and SCOPUS ID: 36731553900 among others. Area of Expertise or Research and Innovation Areas: not limited to energy/greenhouse gas analysis/management, life cycle assessment, application of artificial intelligence techniques, and 3D Modelling**.**

Olatunde Joseph Oloyede graduated from the University of Lagos, Nigeria with a Bachelor's Degree in Mechanical Engineering in 2021. He is currently on one-year mandatory service to his nation in a consulting firm. His research interest is centered on Industrial Engineering and the application of modern analytical methods to carrying out research**.** He is very much interested in carrying out further researches in the engineering field.