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Review

Sustainable Rail/Road Unimodal Transportation of Bulk Cargo in Zambia: A Review of Algorithm-Based Optimization Techniques

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Abstract: Modern rail/road transportation systems are critical to global travel and commercial transportation. The improvement of transport systems that are needed for efficient cargo movements possesses further challenges. For instance, diesel-powered trucks and goods trains are widely used in long-haul unimodal transportation of heavy cargo in most landlocked and developing countries, a situation that leads to concerns of greenhouse gases (GHGs) such as carbon dioxide coming from diesel fuel combustion. In this context, it is critical to understand aspects such as the use of some parameters, variables and constraints in the formulation of mathematical models, optimization techniques and algorithms that directly contribute to sustainable transportation solutions. In seeking sustainable solutions to the bulk cargo long-haul transportation problems in Zambia, we conduct a systematic review of various transportation modes and related mathematical models, and optimization approaches. In this paper, we provide an updated survey of various transport models for bulk cargo and their associated optimized combinations. We identify key research challenges and notable issues to be considered for further studies in transport system optimization, especially when dealing with long-haul unimodal or single-mode heavy cargo movement in countries that are yet to implement intermodal and multimodal systems.

Keywords: greenhouse gases; intermodal; mathematical optimization; multimodal; rail/road transportation; sustainable transport; unimodal

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1. Introduction

In the last few years, there has been growth in the use of mathematical optimization in finding optimal routes for the planning of transportation systems (rail, road, water and air transportation). These optimization techniques have mostly been aimed at reducing carbon dioxide emissions and related costs [1]. Consequently, the reduction of CO_2 emissions in transportation has been the focus of what could be determined as sustainable transportation. However, sustainable transportation is more than just emission reduction as defined by Litman [2]. Litman mentions that sustainability encompasses economic, social and environmental concerns from long-term impacts of transportation. Despite agreeing with most researchers seeking sustainable transportation modes, Litman further gives guidance to the fact that desired values can be obtained by understanding the presumed assumptions and effects of different types of experiments.

Figure 1 illustrates three major issues that mathematical models and algorithms seek to address under sustainable transportation mechanisms.

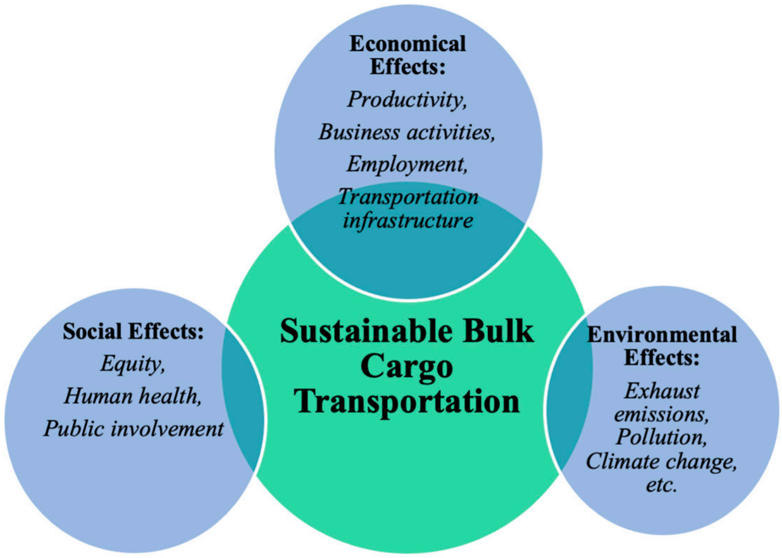

Figure 1. Direct and indirect effects of transportation [2].

Landlocked countries such as Zambia have seen an increase in the transportation of bulk mining cargo by either road or rail without consideration of long-term transportation sustainability. Countries like Indonesia [3] with over 31% rail freight of the total transport freight share have researchers working on the optimization of the rail transport sector to improve its operations. China is equally yet to fully develop it's freight carbon dioxide emission optimization models at a provincial level [4]. This level of research based on modal optimization for sustainable transportation still remains a niche in developing countries such as Zambia. As Zambia is poised to increase its annual copper production from the current annual production of eight hundred thousand (800,000) to three million (3,000,000) tons [5], a need arises to develop local monitoring mechanics as bulk cargo is being transported on the existing two main rail/road networks. For Zambia, being one of the major producers of copper concentrates and copper cathodes, it's transportation routes to the ports of Dar es salaam, Walvis Bay and Durban are mainly by rail and road networks and this compelled the government of Zambia to introduce a law forcing transporters to divert 30% [6] of bulk mining cargo towards the rail network without prior study.

This work focuses on the local and regional impacts of the transportation of bulk cargo and specifically bulk mining cargo. For our study, we have picked Zambia as our locality of reference because of it being a major copper producer with a unimodal transport system. Further pushes by the local government to move mining cargo to rail has motivated us to conduct this study. We feel the local transport variations would have a ripple effect on the regional and global movement of bulk cargo as most copper shipments in Zambia are destined for Asia via several regional countries. In this regard, this paper highlights the opportunities available for mathematical optimization in bulk cargo transport programming with the aim of ensuring long-term sustainability. This particularly for a country like Zambia that relies on a unimodal mechanism of transportation (either road, rail or a combination).

This study further explores various intervention mechanisms carried out across different continents towards the sustainable transportation of cargo. Generally, sustainable transportation goals can be achieved through good planning and the proper use of mathematical optimization techniques. There have been several papers on the performance of multimodal and intermodal transport systems along with proposals of associated optimization techniques aimed at transport sustainability. However, this paper focuses on single-mode (unimodal) transport system optimization techniques that may be valuable for application in landlocked countries like Zambia that rely mainly on unimodal transportation.

As part of the survey, we conducted an exhaustive search of scholarly articles to identify papers published in the area of optimization and sustainable freight transportation. The keywords were intermodal, multimodal, unimodal, optimization and sustainability. No study has been conducted in a situation where rail and road systems are independently used for long-haul bulk mining cargo transportation towards the same destinations under a real driving environment, a position that has created a problem in national bulk cargo freight emission policy regulation formulation. This calls for more research to be conducted for the optimization of unimodal transportation systems in situations where there are disparities in rail/road cargo share where each transport mechanism wants a larger share of the bulk cargo while ignoring the emission concerns.

In summary, this paper makes the following key contributions:

1. We present an up-to-date review of the application of mathematical optimization in sustainable transportation of cargo with a focus on unimodal transport systems suitable for landlocked countries.
2. For the reviewed transport models, we identify the key challenges in implementation suitability for a developed country like Zambia.
3. We provide potential solutions for adaptation of these optimization models to suit the Zambian transport system for bulk mining cargo and ultimately enable the drive towards sustainability.

The rest of the paper is laid out as follows: Section 2 discusses work related to the focus of this survey paper while highlighting the unique contributions of this work and Section 3 discusses the available mathematical optimization models for sustainable transport. Section 3 is segmented to discuss three transportation modes, namely intermodal, multimodal and unimodal which is the focus of this work. In Section 4, we shift focus to the effect of cargo overloading, an aspect that affects rail/road sustainability. Here, we try to highlight how cargo weight plays an important role in the mathematical optimization model for sustainable transport. Section 5 discusses the lessons learnt in this review and it is in this section that implementation and research challenges are discussed. The paper is then concluded in Section 6 with potential solutions and future works discussed therein.

2. Related Work

This section presents several works in the area of long-term sustainability for the transportation of cargo based on mathematical optimization approaches. The work in this paper draws attention to the Zambian long-haul freight system which is similar to most developing countries. Zambia's rail/road long-haul routes are well defined and not prone to any obstructions like buildings because the Zambian government has assigned some independent deviations in some high-density areas. An illustration of a single-mode long-haul freight system being practiced in Zambia is shown in Figure 2. Loading bays are mining companies' warehouses whilst the offloading points are the exit ports of Dar es Salaam (Tanzania), Walvis-bay (Namibia) and Durban [7].

Before we can streamline efforts towards sustainable transports in Zambia, it is essential to look at related applications from the research. For example, Diaz-Parra et al. [8] present an algorithm that solves the planning, routing and scheduling problems presented under land transportation to minimize transportation costs and transit time. In their work, a school bus routing solution using a mixed integer or non-linear mixed integer programming model is used to minimize operational and cost-related problems where the number of buses is regarded as the variable. The authors Wu et al. [9] agree with Diaz-Parra et al. [8] on the importance of routing planning in transportation. However, Wu et al. [9] developed a Non-Dominated Sorting Genetic Algorithm II (NSGA-II) to solve the localized problem of route planning during the transportation of hazardous materials across the city of Guangzhou, China where the authors endeavor to reduce the costs and risks as a result of the transportation of hazardous materials.

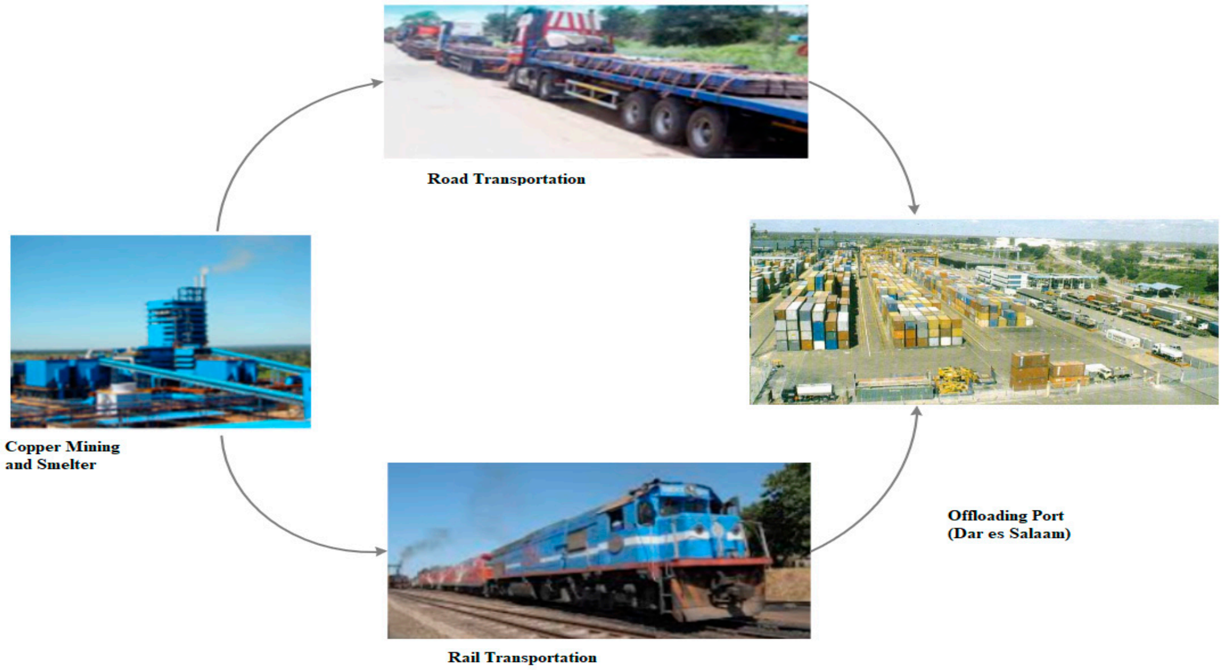

Figure 2. Illustration of single-mode road/rail long-haul transportation to Dar es Salaam.

Despite Wu et al. [9] and Diaz-Parra et al. [8] having contributed to the solution of transportation problems in network routing where transit time and distance between the sources and destinations are considered in the development of solution models, parameters related to emissions are not considered.

On the other hand, Archetti et al. [10] looked at long-haul freight as an integral transport system of road, sea and rail. The authors propose similar modal shifts as a requirement for the reduction of emissions and other costs while recommending unimodal transportation as a preference when transportation distance increases. This has also been supported in several works including [10–15].

While there is a mention of emission reduction in [10], there is no mention of emission reduction in [8]. In agreement to [10] on the reduction of emissions in transportation, the authors Fan et al. [16] conducted a search on publications that concern topics on transportation and carbon emissions using the bibliometric method for the period 1997 to 2023. The authors present that the major contributor to carbon dioxide emissions during transportation is the energy use (fuel consumption). Despite researchers [10] proposing modal shift as a solution towards transportation emissions reduction, the authors in [16] still argue that more emission collection methods still need to be improved to obtain more usable emissions data. The demand for sustainable transportation in the area of greenhouse gases (GHGs) has recently increased prompting [17] to develop a model to calculate road traffic emissions on German transport networks. Two major situations were considered in the development of the model, namely the free and regulated modes. Under the free mode, the tests were conducted without any controls or constraints while the regulated mode meant the tests were under certain conditions such as emission limits. Though their findings showed a reduction of nitric oxide by 32% and 13% particulate matter under the regulated mode compared to the free mode, their study left out the critical greenhouse contributor carbon dioxide in their analysis [18]. The authors recommended the use of the developed model outside Germany; however, the exclusion of carbon dioxide emissions may not be very useful for developing countries. CO_2 emission analysis is critical in developing countries due to the presence of old, disposed-of vehicles imported from developed nations.

Further, Praveen et al. [19] present a survey on several optimization algorithms to help in identifying those that would provide optimal vehicle routing values and reduce on environmental emissions when they are all subjected to similar conditions and parameters.

They conducted studies on several algorithms that include Simulated Annealing, Genetic Algorithm, Anty Colony Optimization [20], Discrete and Improved Bat Algorithm (DaIBA), Evolutionary Simulated Annealing [21], BAT Algorithm and Firefly Algorithm (FA). Results in their work showed that the Discrete and Improved Bat Algorithm (DaIBA) provided a better optimal solution when compared to other algorithms.

However, without infrastructure planning, transportation routing studies cannot be conclusive. To resolve these existing challenges in transportation infrastructure planning and maintenance, studies were conducted to develop optimization techniques that could be used to easily resolve the challenges in road network infrastructure restoration. The existing needs and transit time were used as part of the parameters in developing the bi-objective bi-level optimization model by [22]. Although the impact on the environment was not directly mentioned in their study, the development of optimization models for infrastructure improvement affects the transit time, consequently affecting emission of greenhouse gases.

Apart from the route selection algorithms, Ref. [23] believed that when people share transport facilities with cargo, this would reduce the adverse effects on the environment and traffic congestion. A survey on various studies on shared mobility were conducted with a consideration of model parameters and constraints such as routing, time, loading capacity, cost, and synchronization. The objective functions in this study were grouped into operational and quality-oriented categories. It was assumed that when people park their vehicles to use one car during travel, traffic jams occur due to the increase of vehicles on the road. The reviewed literature was grouped according to problem variations such as dynamic ride sharing (DARP) and solution methods of either exact or heuristic approaches. Mourad et al. [23] further proposed more research to be conducted to develop new models on the shared mobility of people and cargo transportation so that environmental matters can also be addressed. However, the environmental concerns have been brought to the attention of other authors such as Gandhi et al. [12] and Heinold et al. [24].

Heinold et al. [24] reviewed emission estimation models using the methodologies for estimating air pollutant emissions from transport that give real outputs of the emitted greenhouse gases from rail transportation, while other surveys conducted in the area of railway systems concern the improvement of train time scheduling and management. Han [25] conducted a survey study on works solving vehicle routing problems to identify gaps and make necessary proposals that would improve the optimization models and algorithms that were earlier developed. The notable constraints seen in the study were the time and distance (route). System dynamic modelling was performed by [26] to scrutinize the improvements made to the earlier system dynamic mathematical models. Despite Han [25] modelling time and distance problems, Prabowo [3] had earlier considered cost and efficiency as the major problems that needed to solved in Indonesia by considering modal shifts of rail and road systems. The study assumed that it is cheaper to transport goods by road when the transportation route is up to 350 km but expensive beyond that. The motivation for the optimization of the railway transport systems was derived from the lack of innovation by the main railway company and the discovery that cargo customers preferred transportation of their goods by road (trucks) to transportation via railways.

Prabowo's study [3] follows an earlier study by [27] that reviewed optimization models and algorithms to distinguish parameters used in the development of the routing models and algorithms in multimodal transportation.

Table 1 provides a summary of the related works covered in this section in comparison with what is covered in this work.

Table 1. Summary of related work and solution approaches.

Ref.	Title	Solution Approach Parameters				
		Transport System (Modal)	Transportation Cost per Ton-Kilometers and Road/Rail Maintenance	Exhaust Emissions (Kilograms/Ton-Kilometers) under Real Driving Conditions (RDC)	Time (h)	Distance (km)
[10]	Optimization in multimodal freight transportation problems: A Survey	Multimodal	√	×	×	√
[8]	A Survey of Transportation Problems	Multimodal	√	×	√	×
[25]	A Survey for Vehicle Routing Problems and Its Derivatives.	Multimodal	×	×	√	√
[28]	A review of online dynamic models and algorithms for railway traffic management.	Multimodal	×	×	√	√
[23]	A survey of models and algorithms for optimizing shared mobility	Multimodal/Intermodal	√	×	×	√
[19]	A Survey on Various Optimization Algorithms to Solve Vehicle Routing Problem	General	×	×	√	√
[9]	Multi-class hazmat distribution network design with inventory and superimposed risks	General	×	×	√	√
[16]	A review of transportation carbon emissions research using bibliometric analyses	General	×	√	×	√
This Survey	Sustainable Rail/Road Transportation of Bulk Cargo: A Review of Algorithm-Based Optimization Techniques	Unimodal	√	√	√	√

3. Transport Optimization Models for Cargo Movement

3.1. Intermodal Transport Optimization

Intermodal transportation is the movement of a single cargo from one transport system to a different transport system but under different transfer contracts [29]. Sörensen et al. [30] proposed the improvement to the mathematical modelling of the intermodal transport system by considering various parameters and constraints in the transportation problem formulation. The proposed problem parameters with symbols from the general transportation problem formulation are considered as follows:

All customers to be considered (set notation, I),

Proposed locations (set notation, K),

Goods to be transported from i to j (notation, q_{ij}),

Cost of transportation through route ij (notation, C_{ij})

Transportation cost if part of the goods from route ij are transported via terminals k and m (notation, ${C_{ij}}^{km}$),

Loading capacity of terminal k (notation, C_k),

Building cost (fixed) of terminal k (notation, F_k).

As is always the case when formulating a mathematical model, the following variables were considered in the model improvement:

y_k: considered as a binary variable where the binary is 1 when k is a terminal and 0 when not,

w_{ij}: when part of q_{ij} is transported from i to j without diverting,

x_{ij}^{km}: When part of q_{ij} is transported from i to j through terminals k and m

The main objective of the authors [30], was to reduce costs and the following objective function was developed:

$$\text{Min}, \sum_{i,j\in I} \sum_{k,m\in K} c_{ij}^{km} x_{ij}^{km} + \sum_{i,j\in I} c_{ij} w_{ij} + \sum_{k\in K} F_k y_k \text{ (Objective function)}$$

The constraints considered in their study are as follows:

(1) $x_{ij}^{km} \leq q_{ij} y_k \;\; \forall_k, m \in K, \forall_i, j \in I,$
(2) $x_{ij}^{km} \leq q_{ij} y_m \;\; \forall_k, m \in K, \forall_i, j \in I,$
(3) $\sum_{k, m \in K} x_{ij}^{km} + w_{ij} = q_{ij} \;\; \forall_i, j \in I,$
(4) $\sum_{i,j \in I} \sum_{m \in K} x_{ij}^{km} + \sum_{i,j \in I} \sum_{m \in K} x_{ij}^{mk} \leq C_k w_{ij}, \forall_k \in K,$
(5) $w_{ij} \geq 0, x_{ij}^{km} \geq 0, x_{ij}^{kk} \geq 0, \forall_i, j \in I, \forall_k, m \in K,$
(6) The value of $y_k \in \{0, 1\} \;\; \forall_k \in K.$

The objective function reduces the sum of the associated costs with unimodal and intermodal transportation modes including the cost of terminal opening. If the terminal k is open, the products must be transported through it due to restrictions (1) and (2). Constraint or restriction (3) guarantees that the total supplies routed both directly and through terminals matches the demand related to each origin/destination pair. Restriction (4) addresses the terminals' limited capacity. Two distinct terminals are needed to satisfy constraints number (5). Furthermore, restrictions (6) ensure that y_k can only take the values 0 or 1 and that the quantities of items carried by road via terminals are not negative. The developed program is a linear one where binary and real variables exit.

Liu et al. [31] developed a cost analysis and route selection logistics optimization model named Geospatial Intermodal Freight Transportation (GIFT) to optimize the containerized soybeans freight flow nationally. The GIFT model optimized supply, demand sharing, routing methods, intermodal cargo transport mode switching and flow distribution with infrastructure capacity as the constraint. However, this study does not consider the cost related to infrastructure maintenance and emission constraints resulting from the bulk transportation of soya beans on road and rail systems.

Wiegmans and Konings [32] cited road transport as a major contributor to congestion, air pollution, increases in accidents and noise as a motivation to develop a model to analyze and compare the transport costs of intermodal inland waterway transport to that of the road system. This was performed to ascertain the variance (fixed and variable) between intermodal and unimodal road transport systems, though the findings were not conclusive because of so many cost factors (fuel, equipment maintenance, labor, cargo handling charges, etc.) that required consideration in their study. Their study, however, did not consider the sustainability of both transport systems in terms of tonnage per kilometer maintenance of the multi-transport networks (rail, road and waterway). However, ref. [33] proposed other cost models for terminal location analysis and operational activities. Mostert et al. [34] hoped to bridge the gap that exists in the research between cargo transportation modes and human external costs as a result of goods haulage at the transport mode selection level by developing an intermodal allocation model in Belgium that would lead to the reduction of operational and other indirect costs (pollution affects medical expenses).

During studies to analyze the preferences between road and rail/road intermodal transport systems in terms of freight costs, Christian Bierwirth [35] used a mixed integer programming model (MIP) to model freight costs from the factories. This followed similar research for Indian Railways under rail–truck intermodal transportation where a mathematical model was developed for pricing and terminal location optimization purposes to ease solutions of optimal freight rates and the matching intermodal terminal sites in Delhi and Mumbai transport routes [36]. However, both studies still lacked vital information on the emission costs emanating from transportation systems that would be helpful in future searches for environmentally friendly transportation.

Another aspect is the use of mixed integer algorithms meant to solve intermodal transportation risks and apportion containers to various transport modes in Turkey by using the fuzzy-based method [37]. The risk factors considered during the evaluation process included human accidents and deaths, emission values and noise levels leading to the conclusion that their method produced a transportation system that was more economical and environmentally acceptable. Their study, however, also had a bias toward intermodal transportation than long-haul unimodal transportation without considering emissions and optimal cargo tonnage in the mathematical model development.

Several research papers reviewed under this section focused on costs, routing and cargo freight timing on mixed rail/road transport systems without much consideration of a single long haul of bulk cargo on unimodal rail/road transportation systems existing in many landlocked countries. The time effect and emissions do not seem to be the main factor in modal choice planning. This drawback encourages researchers to conduct more studies on time-dependent long-haul road or rail freight systems.

The articles cited in this section are summarized in Table 2. The summary gives a clear glance at the direction taken by the researchers in trying to resolve the challenges in intermodal transportation systems.

Table 2. Summary of different approaches highlighted under Intermodal Transport Research.

Ref.	**Transportation Mode**	**Method of Analysis**	**Parameters and Constraints Considered**					
			Infrastructure Maintenance Costs and Investment	**Transportation Cost (Handling and Movement)**	**Emissions (Environmental and Social Effects/Costs**	**Fuel Costs (L/ton-km)**	**Time (h)**	**Distance**
[31]	Intermodal	(Geospatial Intermodal Freight Transportation) GIFT model and GAMS software.	x	√	x	x	x	√
[32]	Intermodal	Intermodal transport problems and analyses model	√	x	x	x	√	√
[33]	Intermodal	General Optimization	√	√	x	x	x	x
[34]	Intermodal	Intermodal allocation model	√	√	√	x	x	x
[35]	Intermodal	Intermodal Transportation Problem (ITP) model- ILOG Cplex 12.1	x	√	x	x	x	√
[36]	Intermodal	Non-linear trucker shipping cost minimization function	x	√	x	x	√	√
[37]	Intermodal	Mixed Integer Programming and Fuzzy methods	x	√	√	x	x	√

3.2. Multimodal Transport Optimization

Multimodal transportation is the movement of cargo from one transport system to another using the same contract or under one logistics company [29]. This section looks at a few techniques towards the solutions of transportation problems. Sun et al. [1] optimizes the freight route selection problem to lower transport costs during goods movement through the multimodal transport networks. Optimization objectives such as emission costs have been presented using fuzzy time windows [38] though both techniques do not consider tonnage under real-driving conditions when considering emission costs.

Despite the routing problem being dominant, researchers in Turkey [39] further optimized travelling time to solve the routing problem in the city of Izmir using round-based transit optimizer routers, transit mode routing and contraction hierarchies on transportation graphs as their first path-finding algorithm. In coming up with the model for optimal multimodal transportation route selection, Huynh et al. [40] used an analytical hierarchy process (AHP) and zero one-goal programs (ZOGP). The multi-objective optimization technique resulted in the solution of an optimal route selection problem in the affected region. However, the cargo weight per fuel distance cost relationship was not properly defined in this research.

Shen and Wang [41] introduced a binary logic and a regression model for the transportation of some grain crops using mixed rail/road transport systems using from United States of America Freight Analysis Framework (FAF2.2) databases. Other information used came from US highway networks and TransCAD. Their study approach, however, did not include the variables in terms of exhaust emissions per tonnage transported in solving their multimodal transportation problem.

The economic and travel desire behavioral changes that accompany transportation infrastructure developments prompted Moeckel et al. [42] to develop a nested multinomial logic mode selection model with the consideration of travel-related costs, distance, transit stations access, transport service frequency, number of transfers and parking costs. The transit station choice model was conducted with consideration of the increase in fuel prices and the corresponding bus services. The authors support investment in long-distance travel infrastructure bearing in mind that the investments to be made would come with other effects such as environmental, social and economic changes.

However, environmental effects on transportation systems changes call for further models to be developed using real-life measured parameters, especially concerning unimodal long-distance bulk cargo hauling and led Kraft and Stanislav [43] to present a model to predict long-distance traffic flows with a focus on road transport in the Czech Republic. The use of data collected from the existing road traffic flows in the development of the model and distance–decay function makes it easier to predict future traffic flows on the highways to be constructed. The above-cited method has a very good intention in landscape planning. However, it is worth recommending that the model should have included bulk cargo capacity tests during planning for future road developments as this determines the life span of the roads. Further, the environmental impacts of the emissions coming from the vehicles involved in long-haul transportation should be considered. Various approaches taken in trying to solve transportation problems under a multimodal system are summarized in Table 3.

Table 3. Summary of different approaches highlighted under Multimodal Transport Research.

Ref.	Transportation Mode	Method of Analysis	Parameters and Constraints Considered					
			Infrastructure Maintenance Costs and Investment	Transportation Cost (Handling and Movement)	Emissions (Environmental and Social Effects/Costs)	Fuel Costs (L/Ton-km)	Time (h)	Distance [44]
[27]	Multimodal	Various (Review)	x	√	√	x	√	x
[39]	Multimodal	Dijkstra's Algorithm	x	x	√	x	√	√
[40]	Multimodal	Analytic hierarchy process (AHP) and Zero-one goal programming (ZOGP)	x	√	x	x	√	√
[41]	Multimodal	Binary Logit Model and Geographical Information System [45]	x	√	x	√	√	√
[3]	Multimodal	Explorative and Comparable descriptive Methods	√	√	x	x	x	√
[42]	Multimodal	Multinomial logit mode-choice	√	√	x	√	x	√
[43]	Multimodal	Statistical program	√	x	x	x	x	√
[10]	Multimodal	General (Uni-modal/Intermodal/Multimodal)	√	√	√	x	x	√

3.3. Unimodal Transport Systems

Problems involving rail and road long-haul single-mode transportation have rarely been explored, especially the use of parameters such as tonnage, transit time, emissions and fuel consumption to solve real-world and real driving problems towards sustainable transportation [46]. Unimodal transportation is receiving less attention from researchers in preference to the multimodal systems as the latter is considered to not be viable when considering intercontinental cargo shipping as highlighted in the literature survey by [10]. The researchers do not consider the unimodal freight system, especially transportation by road, to be a very optimal solution to the transportation problems. They encourage a shift from unimodal to a combination of unimodal and multimodal systems. Despite unimodal transportation being considered a lesser solution to transportation problems, the system still exists in many landlocked countries with no option for alternative transport modes.

Despite many researchers calling for a shift from unimodal transport systems to other modes (multimodal and intermodal), there is a need to do more in terms of real-life challenges because of bulk cargo transportation so that overall sustainable freight service is achieved. This calls for more proactive research activities to optimize this transportation system to develop optimal solutions to social, economic and environmental problems that arise as a result of overwhelming bulk cargo either by road or rail networks.

According to Singh et al. [47], the traditional transportation problem comprises of 'm' sources each creating a limited accessible unit of a specific item and 'n' demand points each having limited interest of that commodity. The particular bulk transportation problems (BTPs) considered by researchers are the single-mode, multi-standards, multi-file and non-raised transportation problems. The single-mode approach involves the reduction of either cost or total time taken during transportation while the multi bulk transportation problem considers more objectives such as minimizing cost, time and damage of goods during transportation. When there are more indices such as source, destination, make of goods, transport modes and usable resources, then a multi-index method is utilized. In this regard, we present the mathematical model approaches provided by Singh et al. [47].

3.3.1. Single Function Formulation

Minimizing cost objective function;

Minimize, $C = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$.

The objective function is subjected to the following constraints;

(1) $\sum_{j=1}^{n} b_j x_{ij} \leq a_i \qquad (i = 1, 2, \ldots, m)$

(2) $\sum_{i=1}^{m} x_{ij} = 1 \qquad (j = 1, 2, \ldots, n)$

(3) The value $x_{ij} = 0$ or $1 (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$. x_{ij} are the decision variables such that;

The quantity of units of the available item is given by $a_i (i = 1,\ 2,\ 3 \ldots, m)$ based at source location i, whereas $b_j (j = 1,\ 2,\ 3, \ldots, n)$ is the unit of the items wanted at destination j. The cost of bulk transportation of a particular item from source i to end point j is given by parameter $c_{ij} (i = 1,\ 2, \ldots,\ n)$ and $x_{ij} (i = 1,\ 2,\ \ldots,\ m;\ j = 1,\ 2,\ \ldots,\ n)$ is the variable of the assumption whether the requirement is fulfilled or not at the demand or destination point j coming from source point i. For this mathematical formulation, $a_i's$, $b_j's$ and $c_{ij}'s$ are all considered as positive real values. C denotes the overall cost of the bulk transportation.

Minimizing time objective function;

To develop the time objective function, the following is considered,

Minimize, $T = max \left\{ t_{ij:} x_{ij} = 1 \right\}$,

Subject to;

(1) $\sum_{j=1}^{n} b_j x_{ij} \leq\ a_i \qquad (i = 1,\ 2, \ldots,\ m)$,

(2) $\sum_{i=1}^{m} x_{ij} = 1 \qquad (i = 1,\ 2, \ldots,\ \text{n})$,

(3) The value of $x_{ij} = 0\ or\ 1 \quad (i = 1,\ 2, \ldots,\ m;\ j = 1,\ 2, \ldots,\ n)$.

T is the overall time taken to transport the bulk cargo from i to j. x_{ij} are the decision variables such that there is 1 if the cargo is transported and if not, there is 0. $t_{ij} (i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n)$ is the bulk cargo movement time from the origin i to destination j. $a_i's, b_j's\ and\ t_{ij}'s$ are positive real figures.

3.3.2. Two-Dimensional Function Assignment

According to [47], the general mathematical model objective functions for both time and cost assignment problems are expressed in the following equations;

For cost minimization;

Minimize, $C = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$

For time minimization

Minimize, $T = max\{t_{ij}x_{ij} : i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\}$.

The letters C and T represent the Cost and Time functions during bulk cargo transportation.

The two equations (cost and time functions) are subjected to the following listed restrictions;

(1) $\sum_{j=1}^{n} b_j x_{ij} \leq a_i \quad (i = 1, 2, \ldots, m)$,

(2) $\sum_{i=1}^{m} x_{ij} = 1 \quad (j = 1, 2, \ldots, n)$,

(3) The value of $x_{ij} = 0 \text{ or } 1 \quad (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$.

The letters m and n represent the origins and destinations of the respective bulk cargo being transported. The quantity of the commodity present at source i is represented by $a_i(i = 1, 2, 3\ldots, m)$ and the demand value at destination j is $b_j(j = 1, 2, 3, \ldots, n)$. The value of $c_{ij}(i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$ is the cost of transportation from i to j and the time taken during transportation is $t_{ij}(i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$. The decision variables describing whether the conditions of destination j are met by the source i are represented by $x_{ij}(i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$ where the variable is 1 if the condition is met and 0 when not. $a_i's, b_j's, c_{ij}'s \text{ and } t_{ij}'s$ parameters are considered to be positive real figures.

Logistic companies would love to transport the cargo of the customers at a lower cost to make some profit. In another development, the cargo owners would love to have their goods transported to the customers or other need areas with fewer costs.

From the literature survey conducted in [10], a source–truck–train–truck–destination cost analysis mathematical model was presented where the authors looked at costs related to network design for long-haul rail services. The objective function of minimizing linear costs in terms of development of infrastructure and associated facilities was presented where N represented origins/destinations and A for a set of connections or routes connecting the origins and demand (destination) points. Parameters considered in the mathematical are listed as follows:

c_{ij}^{-} standing for costs for construction of fixed network (i, j),

c_{ij}^{k} for transportation cost of cargo k along route (i, j),

u_{ij} representing the transportation capacity of network (i, j),

d_i^k being the demand of item k at destination k.

The variables considered in the model are given by the following expressions:

$y_{ij}\ (i, j) \in A$. These parameters are used to model abstract design decisions using integer variables,

Decision variables are such that $y \in \{0, 1\}$ when action is limited to a certain route and $y \in N_+$ represents the number of facilities constructions that include the service capability,

f_{ij}^k, $(i, j) \in A, k \in K$ represents the traffic passing through route (i, j) carrying cargo k.

When y_{ij} decision variables are considered to be binary numbers, the objective function is developed as follows:

Minimize, $\sum_{(i,j)\in A} c_{ij}^{-} y_{ij} + \sum_{(i,j)\in A, k\in K} c_{ij}^{k} f_{ij}^{k}$

This objective function is subjected to the following restrictions or constraints:

(1) $\sum_{j\in N} f_{ij}^k - \sum_{j\in N} f_{ji}^k = d_i^k \ \ \text{i} \in N, k \in K$,

(2) $\sum_{k\in K} f_{ij}^k \leq u_{ij} y_{ij}, \quad (i, j) \in A$,

(3) $f_{ij}^k \geq 0, \quad (i, j) \in A, k \in K$,

(4) $y_{ij} \in \{0, 1\}, \quad (i, j) \in A$

Constraint (1) is there to satisfy the destination demand requirement from the source on a specific route. The route restriction in terms of capacity was fulfilled by constraint (2). The ultimate goal of the research on train/road transportation was to optimize costs related to the movement of goods from the source to the destination via the road and train networks with consideration for the costs of the route and facilities construction. However, constraints in terms of emission levels during transit were not considered during the study.

Problems tackled by researchers in the field of unimodal transportation are not often inspired by real case applications of real size data in order to find solutions that can be effectively used in practice. The majority of the studies analyze the problem without making use of real data and relying mostly on simulated instances.

4. Overview on the Impact of Overloading Cargo on Transport Sustainability

Simulation models have been developed to improve transport systems policy formulation for sustainable bulk cargo transportation and this led to a system dynamic technique. The techniques can be used to determine the possible and the negative situations on parameters like operational costs, social impact costs, accidents and pavement maintenance when roads are subjected to weights beyond stipulated tonnage during stone transportation. Simulation results in studies have shown that with reduced tonnage, there is a corresponding reduction in operational costs [48].

According to [45], an excellent loading policy is relative to the economic and social costs involved. To this effect, Ghisolfi et al. [45] presented a generalized cost function that depended on the vehicle make, road condition, travelling distance, transit time and fixed costs such as toll fees and other related expenses. The general cost function was presented as follows:

$$GC_{v,r,p} = \beta_1 \cdot \left(T_{v,r,p} \cdot CT_{v,r,p}\right) + \beta_2 \cdot \left(L_{r,p} \cdot CL_{v,r,p}\right) + \beta_3 \cdot (CT_v) + \beta_4 \cdot (CF_v) \tag{1}$$

Equation (1) parameters are explained below:

$GC_{v,r,p}$: This represents the general cost as a result of transportation using vehicle v along route (r, p) where r is the terrain type and p is the condition status of the pavement,

$T_{v,r,p}$: Travel time by vehicle v through route type (r, p),

$CT_{v,r,p}$: Cost per travel time using vehicle v via link (r, p),

$L_{r,p}$: Length of route (r, p),

$CL_{v,r,p}$: Cost per unit distance using vehicle v along route (r, p),

CT_v: Toll fee chargeable on vehicle v along a selected route,

CF_v: Represents the fine imposed on overloaded vehicle v and

β_1, β_2, β_3 and β_4 represent perceived values.

Some researchers had earlier utilized a system dynamic model in China to get rid of overloading and to achieve a sustainable means of intercity cargo transportation [49]. The researchers looked at the impacts that arise because of the predominant two types of road freight systems which include the ordinary and express highways. Transporters using the faster road network are subjected to higher tariffs than those that opt for the ordinary route leading to most freight participants shunning the faster routes. This study seeks to assess the results of modal shift efforts and related policies to identify the useful ones that provide sustainable intercity freight systems. This study discovered that there was compliance during the day because of random inspections by route patrol police officers but the situation changes at night as more overloaded vehicles avoid the toll fees along the faster route.

According to Liu et al. [49], there is congestion on ordinary road routes because drivers with overloaded vehicles avoid higher charges at night resulting in unsustainable effects like accidents and road damage. In Nigeria, highway pavement damage has been a source of concern leading to studies to resolve the problem where some of the parameters such as time, handling costs and costs incurred by the government, such as accident compensation and environmental protection activities costs, have been considered [50]. Sustainability in bulk cargo transportation is very important to resolve the overloading on unimodal transport networks, especially the road network in most landlocked countries. It is also proper to appreciate the study conducted in seeking sustainable transport systems modal shifts to reduce truck overloading negative impacts in [48].

Table 4 gives us a further indication that much concern is on infrastructure degradation without equal consideration on the emission rates.

Table 4. Summary of literature related to overloading.

Ref.	Transportation Mode	Method of Analysis	Parameters and Constraints Considered					
			Infrastructure Maintenance Costs	Transportation Cost per ton-km	Emissions (kgs/ton-km)	Fuel Costs (L/ton-km)	Time (h)	Distance
[50]	Unimodal (road)	Weigh-in-motion (WIM) system	√	x	x	x	√	√
[45]	Unimodal (road)	System Dynamics (SD) Model	√	√	x	x	x	x
[48]	General (Uni-modal/Intermodal/Multimodal)	System Dynamics (SD) Model	√	x	x	√	√	x
[49]	Intermodal and Multimodal	System Dynamics (SD) Model	√	√	√	x	x	√

5. Research Challenges and Lessons Learnt

From the reviewed literature, route selection, modal shift controls, transportation time and distance reduction seemed to have been the main cause for transport systems optimization. The research has exposed various approaches and studies hinging on intermodal and multimodal systems and luck of some practical parameter scientific data. However, the summary provided in Table 4 gives a picture that unimodal transportation is much considered in the studies looking at the mitigation of overloading, especially on truck transportation and the cost of transportation encored by transporters.

The second transportation problem receiving much attention is the reduction of transportation distances. Emissions arising from vehicles, trains and other systems have not received much attention in the studies of modal shifts and routing and this can be confirmed by the strategy for low-emission mobility [11] where the European commission sought the intervention of several consultants in coming up with modern techniques and technologies in the optimization of transportation systems. Further proposals were made to improve the emission measurement methods on automotive vehicles by developing more 'real driving' emission measurement tools. In its Regulation (EU) 2019/1242, the European Union and Council of 2019 proposed a new technique of finding out the levels of exhaust emissions for heavy-duty vehicles to simulate quantities of emissions and fuel consumption to determine the impact of fuel consumption and emission levels [51]. All these efforts by the European Union prove that the exhaust emission factor or parameter is paramount in the optimization and determination of a sustainable transportation system, especially when dealing with the transportation of heavy cargo.

The European Union has agreed on strategies to improve on activities to reduce carbon dioxide (CO_2) emissions by introducing efficient vehicle models leading to zero greenhouse gas emissions. These activities of research carried out by the European Union are commendable because carbon dioxide is believed to be the main contributor to the production of greenhouse gases harmful to the environment. Exhaust emission parameters under real driving conditions is very important in the development of optimization techniques, hence the need for efficient equipment to measure it. However, the literature reviewed does not provide overwhelming approaches and data usable for the development of a universal optimization model for bulk transportation control.

6. Conclusions and Future Work

Most of the papers reviewed so far have dealt with the problem of reducing costs related to transportation and distance studies. Unimodal long-haul distance studies have not received much attention as most researchers focus on the improvement of intermodal and multimodal transportation systems. It is worth noting that there is a considerable research gap in bulk cargo rail/road transportation systems emissions and tonnage in landlocked Zambia and other low-income countries where long-haul single-mode rail/road transport system is still the only means of cargo transportation. Additionally, there is an absence of exhaustive, current rail/road emission statistics for Zambia in the scientific literature, and the development of mathematical models of transportation under a real driving environment (RDE) and related parameters like emissions, tonnage, fuel consumption and transit time. All this, while taking into account stipulated government regulations.

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