Article

Designing Efficient and Equitable Freight Services Markets for Sustainable Economic Performance

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ABSTRACT

Despite the indispensability of freight trucking services and truckers' role as critical stakeholders in supply chains, relatively little attention has been paid to analyzing small independent truckers' roles. Shippers often prefer working with larger trucking companies to the detriment of smaller independent truckers, who must grapple with an inherently disadvantageous job market. Furthermore, in the presence of uncertainty or peak demand periods, trucker shortages can pose significant economic challenges for shippers and downstream customers. In this paper, we propose an analytical framework to address these challenges in efforts to enhance the sustainability of the freight service industry. We formulate and solve a weighted bi-objective optimization model that simultaneously maximizes the total profits of both shippers and truckers to design a sustainable freight services market. Further, we leverage Monte Carlo simulation trials to examine how all players in this market can achieve a better solution under uncertainty. Ultimately, after evaluating multiple scenarios, we find that shippers and truckers yield the highest economic benefits under a balanced design that leverages principles of supply chain coordination, while satisfying all demand from shippers. This framework can serve as a decision support tool for policymakers who aim to ensure all stakeholders in the market can become and remain profitable. Based on our findings, this study suggests practical implications on how to consider humanitarian policies aimed at promoting equity for truckers and ensuring the timely shipment of essential products for both shippers and truckers.

KEY WORDS

Freight Services, Economic Sustainability, Supply Chain Coordination, Multi-Objective Optimization, Simulation

INTRODUCTION

Freight services are a critical component of supply chains globally, with truckers playing a vital role in delivering the millions of products that consumers buy online every day – from perishable groceries and precooked meals to books and electronics. In line with the continuing growth of the online and subscription industries, truckers have become indispensable contributors to economic growth and the effectiveness and efficiency of supply chains. This importance is further magnified, as consumers have become increasingly reliant on e-commerce as the world grapples with the ongoing coronavirus pandemic. Large trucking companies tend to benefit from the increased economic activity because of their ability to offer lower prices to clients due to their vast resources (Jung, et al., 2008). As a result, smaller, privately-owned trucking companies struggle to compete in these circumstances, which

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ultimately yield limited opportunities to remain profitable (Jung, et al., 2008; Kim, 2003). With a limited focus on this issue from both an academic and practitioner perspective, there is a need for new market designs that allow all participating stakeholders to have an equitable opportunity to earn a profit. Accordingly, this paper will leverage simulation and constrained optimization tools to propose a new class of transportation market designs to address these challenges.

TRUCKERS ARE BEHIND THE WHEEL

Millions of people rely on truck deliveries, and more than 3.5 million people work as truckers (Day & Hait, 2019; Oatley, 2020). Considering that truckers play a vital economic role in many societies, it is critical to implement sustainable markets that provide trucking companies of all sizes with a fair opportunity to become and remain profitable while simultaneously meeting customer demand in support of sustainable global economic growth.[1] Therefore, this paper focuses on designing markets that facilitate better profitable jobs between large company truckers and smaller independent truckers.

However, since shippers require their freight to be consistently picked up and delivered on time, they prefer working with large company truckers rather than smaller independent truckers, which generally hinders the latter group from easily securing trucking jobs. Ironically, even as small independent truckers struggle with adverse job market conditions, such as double-brokering that causes high cost burden for them due to the commission[2], shippers often have difficulties finding truckers to deliver their products due to trucker shortages (Hooper & Murray, 2017). Coupled with the increasing prevalence of e-commerce, this trucker shortage is projected to increase to 175,000 by 2025 (Costello & Suarez, 2015).

The creation of a balanced market design that allows shippers to efficiently and equitably assign jobs to trucking companies can improve the work environment of the smaller independent truckers, especially since these employees often suffer from low income due to incorrectly assigned jobs (Appel & Zabin, 2019). Further, this new design would reduce the non-value-add time associated with shippers searching for truckers to deliver products on time. Ultimately, this new market design yields improved coordination between all stakeholders in the market and increased their profit for all involved parties.

RESEARCH CONTRIBUTIONS

To achieve the market above, we explore 25 scenarios by solving a multi-period, multi-participant, constrained model. The output of this model is a range of solutions that allocate shipping jobs to truckers in the market, under various objective functions, that are then analyzed and compared to the current conditions to evaluate performance and trade-offs. Additionally, this newly proposed suite of market designs can serve as a platform for developing policy initiatives that would enhance the competitiveness of smaller independent truckers by enabling them to transport high volumes of freight from shippers through collaboration (Islam & Olsen, 2014).[3]

This research paper makes two research contributions as follows:

1. **Applying operations management models to better coordinate shippers and truckers in a centrally managed market:** By leveraging constrained optimization models, we ensure that all shipper demand can be satisfied and the capacity of truckers in the market is utilized more efficiently. This ineffectiveness of the existing market design, where demand often goes

[1] According to the Sustainable Development Goals (SDGs) adopted by the United Nations, promoting sustainable economic growth (Goal 8) and promoting industrialization (Goal 9) are responsible actions that our world should pursue.
[2] US Trucking: More double-brokering ups threat to US truck shippers (joc.com)
[3] Under current conditions, most independent truckers have vehicles that can only deliver a relatively low volume of freight (e.g., vans); company truckers' trucks, on the other hand, can load higher volumes.

unmet, and capacity is under-utilized, is a major challenge faced by the trucking industry globally that requires the use of rigorous mathematical modeling. These models are particularly relevant to the South Korean trucking industry, where these challenges are pervasive.
2. **Designing markets that facilitate sustainable growth for all stakeholders in the market:** By incorporating a weighted, bi-objective formulation into the design, policymakers can evaluate a trade-off of solutions from both the shippers' and truckers' perspectives. Further, by extending this to multiple periods over a finite time horizon, we investigate how improved job allocations between shippers and truckers can lead to sustainable and equitable opportunities in the market, in comparison to the existing market design.

The remainder of this paper is arranged as follows. In the literature review section, we explore related literature that motivated our research. Next, in Section 3, we present the mathematical model for our newly proposed market design and demonstrate our model by sharing numerical results in Section 4. We share policy and managerial implications associated with our findings in Section 5 and conclude our paper in Section 6 by providing key takeaways and future research extensions.

LITERATURE REVIEW

In this section, we examine the related literature in two specific domains – *(i)* analytical models in freight matching and *(ii)* applying sustainable supply chain management principles to transportation markets. Additionally, we highlight gaps in the current literature that our research addresses.

ANALYTICAL MODELS IN FREIGHT MATCHING

The first theme is the application of analytical models in the freight services industry that simultaneously satisfy operational goals while improving and establishing sustainable business practices in competitive markets with multiple stakeholders. These concepts are used to design sustainable market matching mechanisms for the freight services industry. In this context, a market is defined as a system that enables stakeholders, mainly buyers and sellers, to exchange goods, services, and information (Roth, 2018). As it relates to our research, the freight transport market refers to the exchange of freight services and information between shippers and truckers (Jothi Basu, et al., 2015).

From a classical operations management perspective, resource allocation, assignment, and transportation models can be adapted to solve problems by modifying the mathematical formulation to include design criteria that inform how services are exchanged between all stakeholders involved. More specifically, freight service allocation problems are commonly modeled and described by assignment problems and/or transportation problems to match supply with demand (Peng, et al., 2016). Several research studies consider shipper and carrier mechanisms in tandem with a freight assignment model. For instance, Agrawal and Ziliaskopoulos (2006) examine such markets, where shippers aim to minimize their cost and carriers aim to optimize their individual operations within the freight assignment system. He, et al. (2012) solve an integer linear programming model as part of a multi-criteria decision-making approach that considers both qualitative and quantitative factors that used by transshipment service network managers to minimize a company's logistics costs.

Moreover, when applied to the freight services industry, transportation matching models extend classical vehicle routing and/or load assignment mathematical models to allocate shipping loads to drivers in the market (Masoud & Jayakrishnan, 2017). Most of the research aims to find the least cost assignment of loads to trucks under deterministic load, size, location, and time constraints (Heidari, et al., 2018; Hu, et al., 2018; Zolfagharinia & Haughton, 2017). Given the rapid development of technology, recent studies consider the freight-matching concept with real-time information sharing given multiple periods (Lin & Lee, 2018; Qi, et al., 2018; Wang & Regan, 2002; Yang, et al., 2004).

As previously mentioned, our research utilizes operations research methods to determine the optimal freight matching mechanism between shippers and truckers that satisfied network demand and ensures that all truckers have the opportunity to become profitable by accepting multiple shippers' shipment requests. Such designs yield sustained economic performance. Therefore, in the next section, we survey the literature on the topic of leveraging supply chain management principles to design sustainable transportation systems.

APPLYING SUSTAINABLE SUPPLY CHAIN MANAGEMENT PRINCIPLES TO TRANSPORTATION MARKETS

The second research theme of this paper focuses on sustainable supply chains for the trucking industry. Sustainability systems "*align strategies and operations with universal principles on human rights, labour, environment and anti-corruption, and take actions that advance societal goals*" (United Nations Global Compact, 2020). These business practices facilitate economic growth and assist firms in developing or maintaining competitive advantages. In recent years, the scope of responsibility for supply chain organizations has expanded to accomplish these goals, thus ultimately ensuring all stakeholders' long-term sustainability (de Moura and Saroli, 2020). Many companies have adopted the sustainable supply chain principle defined as the '*sustainable flow of products, services, information, and finance to provide maximum value to all corporate stakeholders*' (Wolf, 2011).

The research presented in this paper considers the concept of economic sustainability, which focuses on providing a pathway for all stakeholders to reduce total supply chain costs continuously while maximizing profit (Keeble, et al., 2003). To evaluate performance with respect to economic sustainability, we adopt one of the output indicators from Keeble, et al. (2003), which utilizes financial measurements such as company profitability or supplier's profitability as key performance indicators. More specifically, we consider a system to be a sustainable system based on the concepts of supply chain coordination, which seeks to determine the optimal allocation of resources while maximizing the total profitability of all stakeholders in the market (Li & Wang, 2007). Expanding on this, we assume that the supply chain is vertically coordinated, which implies that all stakeholders (both shippers and truckers) share profits (or losses) proportional to their risk (Sodhi & Son, 2009).

In the supply chain management domain, the literature focuses on supply chain contracts and coordination issues (Akan, et al., 2011; Islam & Olsen, 2014), mainly between the wholesalers (or suppliers) and retailers to achieve sustained economic performance. There are many types of coordination, such as revenue sharing contracts (Cachon & Lariviere, 2005), information sharing (Chen, 2003; Drake & Schlachter, 2008), and allocation rules (Cachon & Lariviere, 1999). To be more specific, collaboration at the operational level in the shipper-carrier context has become increasingly critical to supply chain coordination (Islam & Olsen, 2014) due to driver shortages and fluctuating fuel prices (Fugate, et al., 2009). Based on the mutual sharing of resources for utilization, supply chain coordination is a critical driver in achieving an economically sustainable supply chain (Dubey, et al., 2017). Consequently, this study explores how the concept of supply chain coordination leads to equitable market designs for all stakeholders, where all network demand is satisfied, and tonnage assignments to truckers are made fairly, which leads to overall profitability of the system and economic sustainability.

In a nutshell, while there are many prior studies on shipper-carrier assignment problems in the freight markets, the research in this field is dominated by the application of operations research methods (both proactively and reactively) to determine the optimal operational decisions within a network that either minimize costs or maximize profit. Our research extends this class of assignment models to facilitate matching shipping jobs with truckers to satisfy all network demand with enhanced capacity utilization while simultaneously ensuring that truckers of all types have equitable access to jobs. Additionally, we examine the behavior of our design over multiple periods. This leads to a well-coordinated supply chain and sustainable economic opportunities for all stakeholders in the market.

MATHEMATICAL MODEL

In this section, we introduce our multi-period, weighted bi-objective optimization model that examines the multiple scenarios for sustainable freight market services. Additionally, we provide the assumptions and justifications for our model along with a detailed mathematical formulation. The freight market under investigation in this paper is comprised of multiple shippers and truckers who operate simultaneously to ensure that all jobs in the market are fulfilled. Specifically, the shippers' jobs can be assigned to either large company truckers or smaller independent truckers (Andres Figliozzi, et al., 2003). To formulate and solve our model, we have made the following assumptions:

1. All shippers and truckers participate in a centralized market, where shipping jobs are allocated to available truckers. In our multi-period, bi-objective model, we determine the optimal allocation of jobs that maximizes the weighted combination of total shippers' profit and total truckers' profit.
2. Demand for jobs is given on a periodic basis. We assume that the planning horizon is fixed, with periodic job allocation decisions in accordance with the demand profile. Similar assumptions have been made in practice by other freight matching services such as Uber Freight (Ganapathy, 2016).
3. Each job in the market may be fulfilled by multiple truckers based on their available capacity. This assumption is informed by the research of Özener and Ergun (2008), which shows that, under a similar design, shippers obtain better freight rates or profit margin, and the truckers utilize their capacity more effectively.
4. Informed by the trucking practices (Luciew, 2012; Ziobro, 2019), both large company truckers and smaller independent truckers provide equal service quality for the freight service.
5. All unit costs are exogenous and are inelastic as it relates to stakeholder behavior. This is in accordance with sustainable freight market research practices as well as industry practices (Luciew, 2012; Ziobro, 2019).

Next, we present the mathematical formulation of a multi-period, weighted bi-objective optimization model to explore freight services designs. In addition to the previously presented assumptions, notation details for the model are given in Tables 1 through 3. Sets and indices are given in Table 1, and Table 2 defines the decision variables regarding the mathematical models. Additionally, Table 3 indicates model input parameters.

Table 1. Sets and Indices

Index	Description	Set
I	*Set of individual shippers*	$i \in I$
J	*Set of individual truckers (inclusive of large company truckers and smaller independent truckers)*	$j \in J$
T	*Set of periods*	$t \in T$
K	*Set of all scenarios to be evaluated*	$k \in K$

Table 2. Decision Variables

Index	Description	Unit
f_{ijtk}	*Tonnage allocated from shipper i to trucker j in period t of scenario k* *(Note: $f_{ijtk} \geq 0, \forall i, \forall j, \forall t, \forall k$)*	*ton*

Table 3. Model Input Parameters

Index	Description	Unit
q_{itk}	*Revenue for the shipper i if the job is done in time t of scenario k*	*$/ton*
y_{ijtk}	*Transportation cost per ton paid by shipper i to trucker j in time t of scenario k*	*$/ton*
c_{jtk}	*Operating cost per ton for the trucker j to do the job in time t of scenario k*	*$/ton*
d_{itk}	*Total tonnage demand (or job requirements) of shipper i to be shipped in time t of scenario k*	*ton*
v_{jk}	*Total truck capacity of trucker j to be accepted of scenario k*	*ton*
w_{Ship}	*Weight assigned to total shippers' revenue objective function*	*%*
w_{Truck}	*Weight assigned to total truckers' revenue objective function*	*%*
p_k	*Probability of scenario k*	*Unitless*

OBJECTIVE FUNCTION DESIGN

As previously mentioned, we propose a multi-period, weighted bi-objective model to evaluate various market designs. The objective function for this model, given in Equation (1), has two major components – *(i)* total shippers' revenue and *(ii)* total truckers' revenue. The weights w_{Ship} and w_{Truck} are the associated weights assigned to each of these components, respectively. Both w_{Ship} and w_{Truck} are non-negative, and w_{Ship} + $w_{Truck} = 1$. We introduce these weights in the objective function to evaluate how the matching decisions and overall distribution of jobs differs from the perspective of both shippers and truckers in the market.

An individual shipper's profit is calculated by taking the difference between the job revenue (q_{itk}) and the transportation cost (y_{ijtk}) and multiplying this value by the associated tonnage allocation (f_{ijtk}). To calculate total shippers' profit, these values are summed over the indices *i*, *j*, and *t*. Similarly, an individual trucker's profit is calculated by taking the difference between the transportation revenue (y_{ijtk}) and operating cost (c_{jtk}) and multiplying this value by the associated tonnage allocation (f_{ijtk}). To calculate total truckers' profit, these values are summed over the indices *i*, *j*, and *t*.

Furthermore, to fully assess how these market designs are impacted by uncertainty, for each scenario *k* (with probability p_k), we simulate realizations of the input parameters (q_{itk}, y_{ijtk}, c_{jtk}, d_{itk}, and v_{jk}) with a coefficient of variation (CV) of 0.5, which shows the level of dispersion around the mean (Rodgers, et al. 2019). Thus, the objective function given in Equation (1) is the expected weighted sum of total shippers' profit and total truckers' profit.

$$\max_{f_{ijtk}} z = \sum_k p_k \sum_i \sum_j \sum_t \left[w_{Ship} \left(q_{itk} - y_{ijtk} \right) f_{ijtk} + w_{Truck} \left(y_{ijtk} - c_{jtk} \right) f_{ijtk} \right] \quad (1)$$

MODEL CONSTRAINTS

As part of the formulation, we consider two classes of constraints given by Equations (2) and (3). Details for these constraints are as follows. Ultimately, the proposed model seeks to maximize Equation (1), subject to the constraint sets given in Equations (2) and (3). Furthermore, the decision variable, f_{ijtk}, is continuous and non-negative. The resulting model is linearly formulated and can be solved to optimality.

CONSTRAINT SET 1 – SUPPLY AND DEMAND REQUIREMENTS

The mathematical representation for this set of constraints is given in Equation (2). For each scenario, *k,* the total tonnage allocation for a given shipper in a specified period must be equivalent to the shipper's demand requirement in that period. The left-hand side of this equation is summed over the index *j*, which indicates that each shipper's demanded tonnage requirement in each period can be divided across multiple truckers. The right-hand side of this equation is the individual shipper's demand in each period. This constraint holds for all shippers in the market in each period in each individual scenario.

$$\sum_j f_{ijtk} = u_{itk},\ \forall i, \forall t, \forall k \tag{2}$$

CONSTRAINT SET 2 – TRUCKING CAPACITY LIMITS

The mathematical representation for this set of constraints is given in Equation (3). Equation (3) delineates a crucial set of constraints that regulate the allocation of total tonnage from multiple shippers to individual truckers within defined time periods while ensuring that this allocation does not exceed the trucker's capacity. On the left-hand side, the notation represents the summation operation, implying that we are summing the tonnage allocated by various shippers (indexed by 'i') to a specific trucker. On the right-hand side, denotes the maximum capacity of the particular trucker ('j') in the context of the given scenario ('k') and time period ('t'). This capacity signifies the upper limit for the amount of tonnage that a trucker can transport within a specific scenario and period without exceeding their operational capabilities. This constraint is universally applicable to all truckers operating within the market, across all time periods and scenarios considered in the model. Its primary purpose is to ensure that the total tonnage allocated to any trucker remains within their operational capacity limits, thus preventing overloading or overcommitment of resources.

$$\sum_i f_{ijtk} \leq v_{jk}, \forall j, \forall t, \forall k \tag{3}$$

CASE STUDY

DATA

In this section, we utilized real-world data from an online freight platform in the South Korean trucking industry to showcase the practical applicability of our model. The dataset, obtained from a prominent logistics company, covers January 2017 to August 2017, and includes 140 carefully matched transactions between shippers and truckers[4]. Each dataset entry contains unique identifiers for shippers, requested tonnage (representing demand), detailed information on the matched truckers, and the specific tonnage allocated to each truck for every transaction.

[4] We used 140 successful matching cases based on Park, et al. (2019) and Park, et al. (2023).

The dataset that obtained does not clearly identify which truckers are company truckers vs. smaller, independent truckers; we developed a simple category system to make this distinction. Based on related literature, two key indicators of a trucker's firm's scale are based on the tonnage volumes of their jobs (The Korea Transport Institute, 2021) and their revenue (noted as transportation costs in our model, this is truckers' revenue). According to The Korea Transport Institute (2021), independent truckers should have just one truck with less than five tonnage trucks. Also, Gallo and Christensen (2011) and Korea Fair Trade Commission (2019) specified the size of companies based on revenue. We calculate the percentile for each of the real trucker's tonnage allocation and their revenue and classified the trucker types.[5] In sum, 92 independent truckers and 48 company truckers are defined. We note that company truckers consume approximately 66% of the total demand in the current market system, whereas independent truckers consume 34%.

In addition, there are several parameters in the model that could not be obtained from data. To bridge this gap, we rely on commonly used assumptions from industry and relevant academic literature, as well as simulation procedures. To estimate the parameter c_j, we assume that 40% of an independent trucker's revenue for a particular job is earmarked for operating costs (Jung, et al., 2008). This is because independent truckers assume responsibility for all relevant operating costs, such as insurance, truck payment, and permits (Luciew, 2012). On the other hand, company truckers assume less responsibility for operating costs since these activities are performed in-house. Because of this, we assume that company truckers pay 20% of their unit revenue to satisfy unit operating costs (Jung, et al., 2008).

The optimization models presented are formulated as linear programs (LPs) in Section §Mathematical Model and are solved with a LINDOGLOBAL solver embedded in the General Algebraic Modeling System (GAMS) tool (GAMS, 2020).

ANALYSIS OF PERFORMANCE INDICATORS

In this section, we examine how the market behaves differently across scenarios. To evaluate sustainability performance, we evaluate profit-orientation, which considers the revenues and costs. First, we explore each stakeholders' profit is that individual stakeholder will maximize their profit. Each stakeholder's profit[6] can be formulated as below:

Shipper profit = shipper revenue – shipper cost[7];
Trucker profit = trucker revenue – trucker operating cost;
Company truckers' profit = company truckers' revenue – company truckers' operating cost; and
Independent truckers' profit = Independent truckers' revenue – Independent truckers' operating cost.

Next, the total profit under supply chain coordination between the shippers and truckers is calculated across various scenarios to analyze the effect of equity and sustainable growth. We calculated the total profit for each market design as follows:

Total profit under supply chain coordination = shipper profit + trucker profit (see Equation 1 in Section §Mathematical Model).

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[5] Using guidance from the ocean shipping industry, we partition shares in the market based on the Baltic Exchange Dry Index that is cargo shipment size that depends on the vessel types (London-based Baltic Exchange, 2019). Based on this indicator, we partition the truckers in the market with a value of 6 as a delineator. For instance, 0-6 values defined as independent truckers and 6-10 values defined as company truckers.

[6] All units are USD.

[7] We assume that a shipper's costs (which are their transportation costs) are equivalent to a trucker's revenue. Profit from both the shippers and truckers are maximized simultaneously in the objective function.

RESULTS

For each market design, we evaluate 25 scenarios with randomized model parameters (from Table 3) sampled from a normal distribution with a coefficient of variation (CV) of 0.5. Each scenario has a corresponding probability, and we maximize the expected weighted sum of the two objective functions simultaneously for each market design. In Table 4, we present various numerical results, given in expected values, for the five different market designs resulting from our optimization output. Business As Usual (BAU) indicates the real-life situation from data. As we examine the trade-off between shippers' and truckers' profits, we observe that the most favorable option for all stakeholders in the market is the balanced market (market design 3). In this particular market design, the risk of lost profits is balanced with the reward of shared profitability for all stakeholders, relative to the other market designs. Further, in comparison to the BAU scenario, the tonnage allocations tend to favor more profitable jobs for both shippers and truckers in the balanced market design (market design 3), thus increasing total profit for these stakeholders relative to the BAU case. Additionally, while the BAU case may have higher tonnage allocation percentages for smaller truckers, these jobs are much less profitable for these stakeholders since this case does not seek to maximize profit.

One of the major inefficiencies seen in the BAU market design is that shipping jobs are assigned to one and only one trucker with available capacity in the current market system. This inefficient assignment scheme is rectified in the newly proposed market designs presented in Table 4, where shipping jobs can be divided amongst multiple truckers while improving capacity utilization in the market. This is driven by the constraint given in Equations 2 and 3, which requires satisfaction of all shipper demand in the market, while simultaneously staying within trucker capacity limits. As previously discussed, market design 3 yields the highest combined profits for all stakeholders in the market and shows the highest profits under the balance market configuration. Market designs 1 and 2 yield similar combined profits, however, since the weights in the objective functions favor the shippers, the truckers in these designs collectively operate at a loss. Market designs 4 and 5, which have objective function weights that are more favorable to the truckers, yield reduced total profits for all stakeholders. Still, profits are split nearly equally between shippers and truckers. Total profit for shippers and truckers is higher than in other markets.

Since our individual market designs maximize the expected weighted sum of total stakeholder profits across 25 randomized scenarios, we investigate the variability of the model outputs. In Figure 1, which displays scenario-level shipper profit results for each market design, we confirm that our observations from the summary-level results in Table 4 hold true upon introducing variability into the model.

Additionally, the results displayed in Figure 2 show that company truckers are significantly more profitable under the balanced market design configuration, even in the presence of uncertainty. In Figure 3, however, independent truckers are most profitable under market designs 4 and 5, which are designed to be more favorable to truckers. But in referring back to Figure 1, market designs 4 and 5 yield significant profit losses for shippers in these instances, which renders these designs less desirable.

Each of these market designs presented in this section lead to improved performance over the BAU case in terms of total profitability and the ability to satisfy all shippers' jobs in the market. Furthermore, in evaluating each of these market designs in the presence of uncertainty, the objective function weights are critical design parameters and drivers in the profitability of all stakeholders in the market. Market designs 1 and 2 lead to significant losses for truckers, but profit increases for shippers. In these designs, jobs are allocated to truckers in a sequence that is most favorable to the shippers in the market. This unfortunately has negative effects on the truckers in the market, with smaller independent truckers absorbing the majority of the profit losses.

Table 4. Sensitivity Analysis Results

	Business As Usual BAU	100% Shipper Profit Max Market Design 1	75% Shipper Profit Max Market Design 2	50/50 – Balanced Market Market Design 3	75% Trucker Profit Max Market Design 4	100% Trucker Profit Max Market Design 5
Expected Tonnage Allocation	*Company Truckers: 66% Independent Truckers: 34%*	*Company Truckers: 71% Independent Truckers: 29%*	*Company Truckers: 94% Independent Truckers: 6%*	*Company Truckers: 78% Independent Truckers: 22%*	*Company Truckers: 6% Independent Truckers: 94%*	*Company Truckers: 3% Independent Truckers: 97%*
Expected Total Shipper Profit ($)	*$99.1K*	*$242.2K*	*$241.9K*	*$221.5K*	*$115.2K*	*$107.9K*
Expected Total Trucker Profit ($)	*$14.2K*	*-$4.5K*	*-$0.7K*	*$22.6K*	*$101.4K*	*$102.8K*
Expected Total Supply Chain Coordination Profit ($)	*$113.3K*	*$237.7K*	*$241.2K*	*$244.1K*	*$216.6K*	*$210.7K*

Note: K indicates $100,000

Figure 1. Shippers' Profit Simulation Trials

Oppositely, market designs 4 and 5 are less profitable for all stakeholders, but profits are split nearly equally for shippers and truckers. However, in these instances, since the objective function weights are more favorable to the truckers in the market, job assignments are made with priority given to jobs that are most profitable to the truckers. This leads to significant profit increases for the truckers, with smaller independent truckers benefitting the most, since their services are more expensive than those of the larger company truckers. Market design 3, which is driven by a balanced market, is the most profitable design, where the risk of lost profits to the shippers is offset by the collective profitability of all stakeholders. In this design, the results suggest that this configuration will lead to sustained financial performance between independent and company truckers. In summary, the numerical results presented in this section demonstrate the applicability of the proposed analytical framework as a decision support tool that aids in the construction of an efficient and equitable market design.

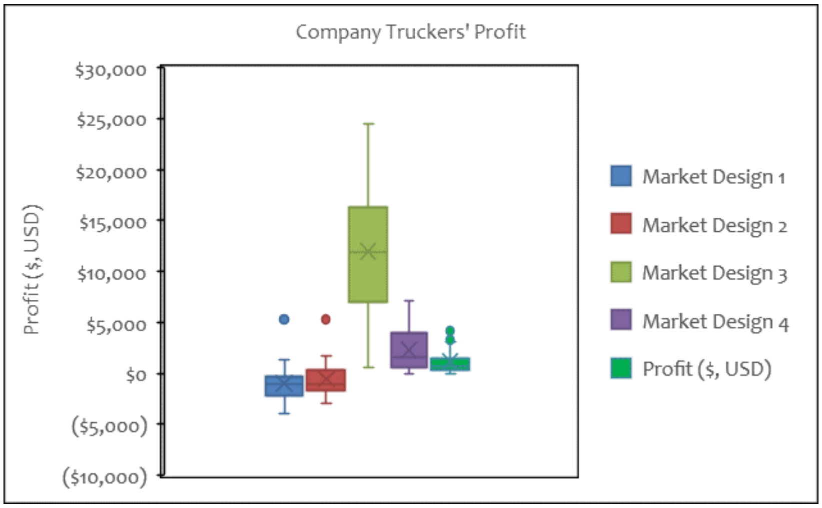

Figure 2. Company Truckers' Profit Simulation Trials

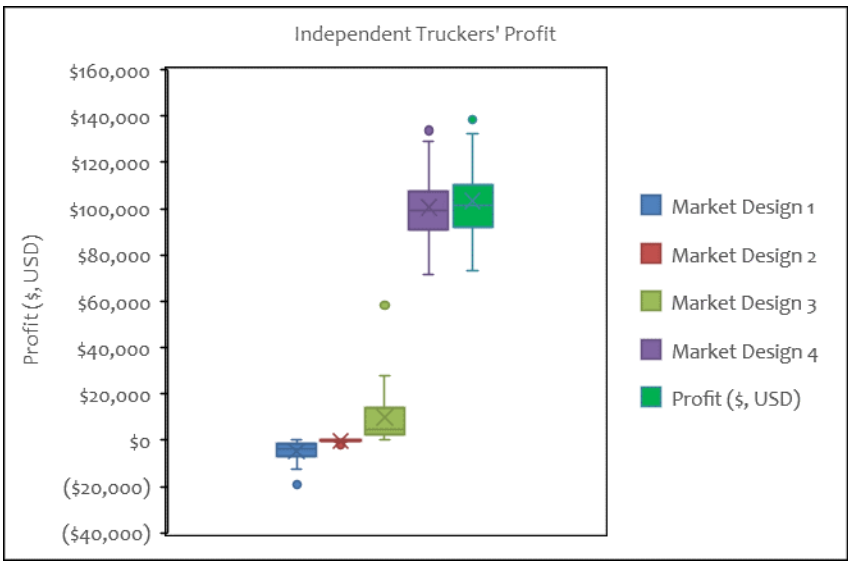

Figure 3. Independent Truckers' Profit Simulation Trials

DISCUSSION

As observed in the numerical results, our proposed framework can serve as a decision support tool when evaluating market designs from different perspectives. However, balancing the needs of all shippers and truckers in the market by utilizing supply chain coordination principles yields improved profitability opportunities for independent truckers while simultaneously satisfying all shipper demand. Furthermore, this newly proposed mathematical framework allows for a more efficient allocation of resources by enabling shippers to divide their jobs amongst multiple truckers. These contributions are significant improvements over the BAU case, where jobs are inefficiently assigned, and independent trucking companies have a limited chance of becoming profitable.

Ultimately, our findings suggest that, for the shippers in the market, our newly proposed framework suggests that they can collectively earn increased profit under a coordinated supply chain design. Since independent truckers also see increased profits under this design, this finding can serve as a springboard for sustained economic growth in this sector. More specifically, this sustainable relationship leads to job creation and may increase the total profit for all stakeholders while giving more job opportunities (United Nations Global Compact, 2020) with enough independent truckers' capacity. Furthermore, this business process can improve the shippers' reputation in the area of sustainable performance (Goessling, et al., 2005).

The numerical results show that their profits are better indications for the company truckers and independent truckers than BAU under a coordinated supply chain. With this in mind, there is a potential shared growth opportunity by collaborating among them (Islam & Olsen, 2014; Santos, et al., 2021). In their relationships, 'shared-power' can be considered through collaboration under sustainable development; that is, participants jointly can share their abilities and information to resolve a problem to achieve their goals (Crosby & Bryson, 2005). For instance, FedEx uses independent truckers' capacity for delivery services "*as contractors, not employees*" (Luciew, 2012) to manage multiple delivery routes and for better freight services (such as operating seven days) while minimizing their costs concerning the company truckers (Ziobro, 2019).

In short, our newly proposed framework can serve as a decision support tool for policymakers to evaluate different market designs under various perspectives. Under the balanced market scenario (market design 3), all shippers, company truckers, and independent truckers achieved the highest total coordination profit. Therefore, policymakers can develop a trucking operational policy by adopting the supply chain coordination concept toward a sustainable market. However, more operational, and policy-oriented research is required to evaluate the feasibility of implementing these practices.

CONCLUSION AND FUTURE DIRECTIONS

In considering the ultimate goals of sustainability to provide for people's basic their needs, it is important to discuss potential ways to enhance the engagement of truckers and expand their profits. In line with these needs, this study proposes a supply chain coordination system for shippers, company truckers, and independent truckers. The proposed system in this paper explores several scenarios and collaboration of all participants shows better financial performance to them. Our analysis shows that the total profitability for all stakeholders would increase relative to current conditions (as described in the BAU scenario) if our proposed system is adopted to the supply chain. Additionally, the proposed designs are more adept at utilizing truckers' capacity to satisfy shippers' demands.

We acknowledge the study's limitations concerning exploring a restricted set of scenarios and its potential influence on the broader applicability of the findings. Our analysis is based on an online freight platform transaction dataset, which may impose constraints on the generalizability of the results. Additionally, our proposed model operates under the assumption of profit-maximizing behavior for all market participants. However, in real-world applications, particularly within the trucking industry, numerous factors such as market dynamics with macro-economic environments (e.g., supply shortages, demand fluctuations) involving shippers and truckers may significantly affect outcomes, deviating from the idealized profit-maximizing behavior assumed in our model.

Therefore, our study can be extended by considering humanitarian policies that advance truckers' equity (via financial or operational support), that would bolster the welfare of multi-stakeholders in the supply chain (i.e., shippers and truckers) and our society at large (i.e., consumers) (Fried, 2020). Indeed, such policies would enable shippers and truckers to manage the high demand for delivery services during unforeseen situations such as the ongoing COVID-19 crisis, when the shipment of essential products and inventories requires ramped up production and distribution efforts (INFORMS, 2020; Marshall, 2020).

REFERENCES

Agrawal, B. B., & Ziliaskopoulos, A. (2006). Shipper–carrier dynamic freight assignment model using a variational inequality approach. *Transportation Research Record,* 1966, 60-70.

Akan, M., Ata, B., & Lariviere, M. A. (2011). Asymmetric information and economies of scale in service contracting. *Manufacturing & Service Operations Management,* 13, 58-72.

Andres Figliozzi, M., Mahmassani, H. S., & Jaillet, P. (2003). Framework for study of carrier strategies in auction-based transportation marketplace. *Transportation Research Record*, 1854, 162-170.

Appel, S., & Zabin, C. (2019). Truck driver misclassification: Climate, labor, and environmental justice impacts. Center for Labor Research and Education, University of California, Berkeley.

Cachon, G. P., & Lariviere, M. A. (1999). Capacity choice and allocation: Strategic behavior and supply chain performance. *Management Science,* 45, 1091-1108.

Cachon, G. P., & Lariviere, M. A. (2005). Supply chain coordination with revenue-sharing contracts: Strengths and limitations. *Management Science,* 51, 30-44.

Chen, F. (2003). Information sharing and supply chain coordination. *Handbooks in Operations Research and Management Science,* 11, 341-421.

Costello, B., & Suarez, R. (2015). Truck driver shortage analysis. American Trucking Association. http://constructionequipment.s3.amazonaws.com/s3fs-public/ATAs%20Driver%20Shortage%20Report%202015.pdf.

Crosby, B., & Bryson, J., (2005). A leadership framework for cross-sector collaboration. *Public Management Review,* 7, 177-201.

Day, J. C., & Hait, A. W. (2019). Number of truckers at all-time high bctv.org. https://www.bctv.org/2019/06/11/number-of-truckers-at-all-time-high/

de Moura, G. B., & Saroli, L. G. (2020). Sustainable value chain management based on dynamic capabilities in small and medium-sized enterprises (SMEs). *The International Journal of Logistics Management*, 32, 168-189.

Drake, M. J., & Schlachter, J. T. (2008). A virtue-ethics analysis of supply chain collaboration*. Journal of Business Ethics,* 82, 851-864.

Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., & Wamba, S. F. (2017). World class sustainable supply chain management: critical review and further research directions. *The International Journal of Logistics Management*, 28, 332-362.

Fried, B. (2020). COVID-19: US forwarders and truckers seek government financial and operational support. Air Cargo News. https://www.aircargonews.net/freight-forwarder/covid-19-us-forwarders-and-truckers-seek-government-financial-and-operational-support/

Fugate, B. S., Davis-Sramek, B., & Goldsby, T. J. (2009). Operational collaboration between shippers and carriers in the transportation industry. *The International Journal of Logistics Management*, 20, 425-447.

Gallo, P. J., & Christensen, L. J. (2011). Firm size matters: An empirical investigation of organizational size and ownership on sustainability-related behaviors*. Business and Society,* 50, 315-349.

GAMS, 2020. CPLEX 12. GAMS. https://www.gams.com/latest/docs/S_CPLEX.html

Ganapathy, V. (2016). Case study: The Uberisation of supply chain. *SAMVAD,* 11, 26-31.

Goessling, T., Jansen, R., & Oerlemans, L. (2005). Coalitions and collisions: The benefits and problems in the context of collaboration. *Coalitions and Collisions*, 385-397.

He, T., Ho, W., Man, C. L. K., & Xu, X. (2012). A fuzzy AHP based integer linear programming model for the multi-criteria transshipment problem. *The International Journal of Logistics Management*, 23. 159-179.

Heidari, F., Zegordi, S. H., & Tavakkoli-Moghaddam, R. (2018). Modeling truck scheduling problem at a cross-dock facility through a bi-objective bi-level optimization approach. *Journal of Intelligent Manufacturing,* 29, 1155-1170.

Hooper, A., & Murray, D. (2017). An analysis of the operational costs of trucking: 2017 update. American Transportation Research Institute. https://truckingresearch.org/wp-content/uploads/2017/10/ATRI-Operational-Costs-of-Trucking-2017-10-2017.pdf

Hu, L., Zhu, J. X., Wang, Y., & Lee, L. H. (2018). Joint design of fleet size, hub locations, and hub capacities for third-party logistics networks with road congestion constraints. *Transportation Research Part E: Logistics and Transportation Review,* 118, 568-588.

INFORMS (2020). From pandemic disruption to global supply chain recovery. https://www.youtube.com/watch?v=17movBpTqts

Islam, S., & Olsen, T. (2014). Truck-sharing challenges for hinterland trucking companies: A case of the empty container truck trips problem. *Business Process Management Journal*, 20, 290-334.

Jothi Basu, R., Subramanian, N., & Cheikhrouhou, N. (2015). Review of full truckload transportation service procurement. *Transport Reviews,* 35, 599-621.

Jung, S., Lee, T., Kwon, H., Lim, D.,& Heo, J. (2008). A study on improvement plan of trucking industry system. *Korea Transport Institute*.

Keeble, J. J., Topiol, S., & Berkeley, S. (2003). Using indicators to measure sustainability performance at a corporate and project level. *Journal of Business Ethics,* 44, 149-158.

Kim, C. (2003). Too many haulers chasing the cargo. Korea JoongAng Daily. http://koreajoongangdaily.joins.com/news/article/article.aspx?aid=1979184

Korea Fair Trade Commission (2019). Competition policy. Korea Fair Trade Commission. http://www.ftc.go.kr/eng/cop/bbs/selectBoardList.do?key=2835&bbsId=BBSMSTR_000000003631&bbsTyCode=BBST11

Li, X., Wang, Q. (2007). Coordination mechanisms of supply chain systems. *European Journal of Operational Research,* 179, 1-16.

Lin, C. C., & Lee, S. C. (2018). Hub network design problem with profit optimization for time-definite LTL freight transportation. *Transportation Research Part E: Logistics and Transportation Review,* 114, 104-120.

Luciew, J. (2012). Independent truck owners carry the weight of FedEx Grounds' business. PENN LIVE Patriot-News. https://www.pennlive.com/midstate/2012/08/independent_truck_owners_carry.html

Marshall, A. (2020). As Covid-19 spreads, truckers need to keep on trucking. WIRED. https://www.wired.com/story/covid-19-spreads-truckers-keep-trucking/

Masoud, N., & Jayakrishnan, R. (2017). A real-time algorithm to solve the peer-to-peer ride-matching problem in a flexible ridesharing system. *Transportation Research Part B: Methodological,* 106, 218-236.

Oatley, S. (2020). As truckers are expected to do more, they are offered less. PT News. https://www.citizenstringer.com/as-truckers-are-expected-to-do-more-we-offer-less/

Özener, O., & Ergun, O. (2008). Allocating costs in a collaborative transportation procurement network. *Transportation Science,* 42, 146-165.

Park, A., Cho, S., Kim, S., & Zhao, Y. (2019). Factors influencing e-procurement adoption in the transportation industry. In: Yang, H., & Qiu, R. (eds) *Advances in Service Science*. INFORMS-CSS 2018. Springer Proceedings in Business and Economics. Springer, Cham.

Park, A., Chen, R., Cho, S., & Zhao, Y. (2023). The determinants of successful online matching platforms for freight services, *Trasportation Research Part E: Logistics and Transportation Review*, 179, 103284.

Peng, Z., Shan, W., Guan, F., & Yu, B. (2016). Stable vessel-cargo matching in dry bulk shipping market with price game mechanism. *Transportation Research Part E: Logistics and Transportation Review,* 95, 76-94.

Qi, W., Li, L., Liu, S., & Shen, Z.-J.M. (2018). Shared mobility for last-mile delivery: Design, operational prescriptions, and environmental impact. *Manufacturing & Service Operations Management,* 20, 737-751.

Rodgers, M. D., Coit, D. W., Felder, F. A., & Carlton, A. G. (2019). A metamodeling framework for quantifying health damages of power grid expansion plans. *International Journal of Environmental Research and Public Health*, 16, 1857.

Roth, A. E. (2018). Marketplaces, markets, and market design. *American Economic Review,* 108, 1609-1658.

Santos, M. J., Curcio, E., Amorim, P., Carvalho, M., & Marques, A. (2021). A bilevel approach for the collaborative transportation planning problem. *International Journal of Production Economics,* 233, 108004.

Sodhi, M. S., & Son, B.-G. (2009). Supply-chain partnership performance. *Transportation Research Part E: Logistics and Transportation Review,* 45, 937-945.

The Korea Transport Institute (2021). 2020 Freight transport market trend Annual report (In Korean). https://www.koti.re.kr/user/bbs/BD_selectBbs.do?q_searchKeyTy=sj___1002&q_searchVal=&q_bbsCode=1093&q_bbscttSn=20210726174721314&q_rowPerPage=10&q_currPage=1&q_bbsSortType=&q_clCode=&

United Nations Global Compact (2020). Who we are. United Nations Global Compact.

Wang, X., & Regan, A. (2002). Local truckload pickup and delivery with hard time window constraints. *Transportation Research Part B: Methodological,* 36, 97-112.

Wolf, J. (2011). Sustainable supply chain management integration: A qualitative analysis of the German manufacturing industry. *Journal of Business Ethics,* 102, 221-235.

Yang, J., Jaillet, P., & Mahmassani, H. (2004). Real-time multivehicle truckload pickup and delivery problems. *Transportation Science,* 38, 135-148.

Ziobro, P. (2019). FedEx, UPS find formula for delivering seven days a week: Discount sunday drivers, *The Wall Street Journal*. https://www.wsj.com/articles/fedex-ups-find-formula-for-delivering-seven-days-a-week-discount-sunday-drivers-11564920000

Zolfagharinia, H., & Haughton, M. A. (2017). Operational flexibility in the truckload trucking industry. *Transportation Research Part B: Methodological,* 104, 437-460.