

A Statistical Assessment of Crowdsourced Last-Mile Delivery Solutions in Smart Transportation Systems: Evidence from Saudi Arabia

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Abstract: This study investigates the impact of crowdsourced last-mile delivery platforms on smart transportation performance, perceived traffic congestion, and sustainable urban mobility in Saudi Arabia. Crowdsourced delivery has become the new dynamic last-mile logistics tool that can affect transport system operation, traffic, and sustainability in this case. The paper focuses on the impact of crowdsourced last-mile delivery on smart transportation performance in Saudi Arabia. The research paradigm assumed by the study was quantitative and was based on the analysis of surveys of 300 users and drivers of the crowdsourced delivery services offered in Riyadh, Jeddah, and Dammam. The findings showed that the more contact with crowdsourced delivery systems, the higher the perception of the efficiency of the transportation system. Moreover, the effectiveness of the transportation systems is positively correlated with more perceptions of reduction of congestion and sustainability. Besides, Structural Equation Modeling established that the connection between the use of crowdsourced delivery platforms and sustainability outcomes is partially mediated by the efficiency of the transportation system, which moderates the relationship. Moreover, the high frequency of using crowdsourcing delivery platforms was also related to a positive attitude towards the exposure of environmental benefits and city mobility. The research suggested that the implementation of crowdsourced delivery services induces the design of smarter and more sustainable urban delivery systems in Saudi Arabia, assuming that the services are accompanied by sufficient digital infrastructure and align with the Saudi Vision 2030 and existing smart transportation initiatives.

Keywords: Crowdsourced Delivery; Last-Mile Logistics; Smart Transportation Systems; Sustainable Urban Mobility; Traffic Congestion.

1. Introduction

The recent few years have seen the delivery of a paradigm change in the logistics sector through crowdsourced delivery. This has been credited to many reasons, including technological innovation, the emergence of e-commerce, and the growth of the gig economy, among others [1]. Crowdsourced delivery has turned out to be a new and efficient way of solving problems related to the last-mile delivery. This mode of delivery is credited especially with the growth of efficiency in operations and the minimization of resource wastage. It employs the data analytics platforms and artificial intelligence algorithms to find routes in real-time and optimize the user experiences. It has come out in different research works that this delivery strategy, combined with smart transportation systems, boosts mobility, reduces road traffic, and minimizes the emission of gases. In different nations across the world, the use of smart technology solutions as one of the strategies of sustainable city development has begun to be implemented. In this respect, crowdsourced delivery has become a significant agent of change, as new trends have appeared. This plan is in line with Vision 2030 strategy, which lays emphasis on economic diversification, sustainable development, and technological transformation. This way, the Saudi government has begun investing in intelligent transport infrastructure and building interrelations between the presence of digital platforms and urban mobility services [6]. Nevertheless, in recent times, there are still numerous issues that face the large-scale use of crowdsourced delivery. It mainly includes vague laws, differences in the working conditions of the freelance delivery people, and growing fears regarding data security [4]. The effectiveness of such a strategy significantly depends on the creation of a sophisticated information infrastructure and a desire by the concerned agencies to regulate such platforms [3]. Research conducted in other countries, including South Africa, Turkey, and Lithuania, suggests that the level of efficiency of the crowdsourced delivery service is highly dependent on the atmosphere existing in that area. Within the framework of Saudi Arabia, where the sizes of the traffic jams in Riyadh, Jeddah, and Dammam continue to rise, crowdsourced delivery may be evaluated as a priceless strategic asset to the efficiency of the transport sector to create smarter transport systems [11].

Taking into consideration these factors, there is an increased demand for analyzing the local context regarding implementing

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this model and the potential contribution it may have in achieving smart mobility and sustainable objectives within the Kingdom, particularly due to the lack of related research within the Gulf region.

The main research problem of this study focused on understanding the effects of crowdsourced delivery systems on Saudi Arabia's transportation system. The research problem exists because scientists have not yet determined how crowdsourced delivery operations affect Saudi Arabia's transportation system, although they anticipated positive results from these systems. Research findings demonstrate that crowdsourcing operations function to reduce traditional logistics systems' operational inefficiencies, yet some experts warn about increased vehicle mileage (VMT), which results from unregulated crowdsourcing operations. The decentralized structure of crowd delivery systems creates obstacles for regulation and worker protection, as well as sustainable freelance delivery operations, because Saudi Arabian metropolitan areas, including Riyadh, Jeddah, and Dammam, face rising traffic congestion, which requires evaluation to determine if crowd delivery will solve or worsen this situation.

Based on the above discussion, and to achieve the main goals of the research, the following research objectives have been formulated:

- The first goal of this research involves studying how crowd-based delivery affects the environment through its ability to reduce empty miles and improve fuel consumption.
- The research will investigate how crowd-based delivery services impact social aspects by studying their effects on urban transportation, service availability, and convenience.
- Freelance logistics economic evaluation focuses on three main areas, which include operational efficiency, cost management, and employment generation.
- The research will study how crowdsourced delivery systems integrate into Saudi Arabia's smart transportation network while assessing their ability to achieve national sustainability goals.

The research attempts to address these main research questions:

1. The study investigates Saudi Arabia's smart transportation systems to understand how crowdsourced delivery services function within these systems.
2. The study investigates how decentralized logistics services affect traffic congestion and fuel consumption rates.
3. The study focuses on how digital platforms working with real-time participation methods produce sustainable urban mobility solutions.

This research is aimed at developing the knowledge and awareness of how a mass transit system affects the transport network in Saudi Arabia. Moreover, the results will help Saudi Arabia overcome regulatory and other issues associated with the development of an improved urban transportation system. Moreover, the paper aims to fulfill the goals of Saudi Vision 2030 associated with smart city projects, digitalization, and green projects. The study of the operation of crowd shipping in the Kingdom gives solutions to the development of effective and adequate transportation networks. Moreover, this study will attempt to fill the lack of knowledge on the effect of crowd shipping on wise transportation infrastructures that strive to reach enhanced urban mobility and sustainability to foster innovation in the Saudi Arabian transportation sector.

2 Literature Review

Crowdsourced delivery has been proposed as an addition to smart transport networks, which have garnered growing interest in the academic community due to mounting congestion, last mile inefficiencies, and sustainability demands in urban logistics. As a digitally mediated coordination mechanism, crowdsourcing has developed out of a general model of participation into well-organized logistical uses that can take advantage of distributed participants and platform technologies [1,20]. It is a dynamic approach that allows the use of occasional or independent drivers in transportation and logistics systems to execute delivery operations, which offers flexibility to the traditional routing and distribution systems [15,17].

In recent analytical reviews, it is stressed that crowdsourced delivery is not an innovation in the mode of operation, but rather a restructuring of logistics networks in a systemic way [9,23]. In terms of operation, these types of models add transshipment points, dynamic assignment procedures, and responsive routing policies that boost the responsiveness during uncertain demand situations [9,15]. Sustainable crowd logistics should be integrated into wider network designs in order to realize efficiency and environmental benefits through the systems-thinking perspective [23]. Empirical studies also show that crowdsourced solutions can enhance the efficiency of parcel delivery and minimize unnecessary traffic flows in vehicles in case of proper coordination [21].

A major facilitator of these systems is still technological infrastructure. Intelligent transportation ecosystems are based on

artificial intelligence, digital platforms, and communication technologies based on the Internet of Things [11,18]. Routing optimization and adaptive traffic management systems built upon AI have been observed to improve the efficiency and reduce congestion in intelligent mobility systems [6,11]. In the context of Saudi Arabia, the development of smart transportation planning is increasingly connected with the national development goals, but the issue of governance, infrastructural integration, and scalability still remains [7,10]. Digitalization has also been placed as a strategic tool in ensuring sustainability agendas under the vision 2030, especially within the circle carbon economy framework [13].

Crowdsourced delivery has a sustainability aspect which has been given special consideration in recent scholarship. Sustainable crowd logistics combines both the environmental goals, which include reducing emissions and preventing congestions, with the social goals like trust, fairness, and platform governance [12,14,19]. At the network level, it has been proposed that a combination of privately and publicly operated transport modalities can be made to help lower ecological footprints in the last mile operations [19,23]. On the behavioral level, technological value, perceived usefulness and trust play important part in further interaction with crowdsourced platforms [12,24]. Furthermore, the perspectives of couriers emphasize the operational limitations and dynamics of the platform to influence the system performance and social sustainability [26].

Typologies of Business models also indicate that the extent of scalability and sustainability also differ according to the structural composition of crowdsourcing delivery arrangements [17]. Peer-to-peer and hybrid models have the potential to prove their viability in new economies as long as they are matched with local infrastructural and institutional set-ups [14,27]. Nonetheless, threats to green crowdsourcing, such as regulatory risks, operational risks, and so on, speak in favor of the necessity of integrated structures that would present efficiency, governance, and sustainability as one [22].

Altogether, the literature narrows down to three insights. To begin with, crowdsourced delivery brings adaptive and decentralized systems that can improve the efficiency of the last mile [9,15,21]. Second, routing, traffic flow and mobility systems can be optimized with the help of digital and AI-enabled infrastructures [6,11,18]. Third, sustainability (environmental, social, and institutional) factor plays a major role in determining the system adoption and viability in the long term [12,19,23].

In spite of these developments, there is very little empirical research that investigates the interaction of the three variables of system efficiency, usage behavior, and sustainability perception in an emerging smart transportation ecosystem, especially in Saudi Arabia. The current research is usually focused on operational optimization [9,15], sustainability results [12,19,23], or the adoption of technology separately. As such, a deep analytical framework that incorporates these dimensions into the Saudi smart mobility framework has not been well explored. The gap is addressed to help in the context of how crowdsourced delivery can not only be a technological complement but also a structural part of intelligent transportation development.

3 Hypothesis Development

Based on the above synthesis, this paper will discuss how crowdsourced delivery can be used in the changing Saudi Arabian environment of smart transportation by connecting operational efficiency, decentralized logistical processes, digital platform implementation, and sustainability processes.

3.1. Crowdsourced Delivery and Smart Transportation Efficiency.

Crowdsourced delivery proposes decentralized and demand-driven models, which create responsiveness in the logistic networks [15,17]. According to the operational research, the responsiveness with the help of flexible allocation of drivers and transshipment-enabled routing can be used to minimize inefficiencies linked to a rigid distribution system [9,15]. Evidence of the effectiveness of crowdsourced couriers in improving service delivery is provided by the empirical evaluations of parcel delivery systems that indicate that digital coordination platforms create the conditions that allow the crowdsourced couriers to become better at performance [21]. In smart roads, traffic optimization and routing algorithms that are powered by AI reinforce the efficiency gains even further [6,11]. Based on this, the hypothesis is as follows:

H1: *Crowdsourced delivery has a positive effect on the efficiency of smart transportation systems in Saudi Arabia.*

3.2. Decentralized Logistics and Vehicle Route Planning.

Decentralized logistics substitutes dispatching centers with real-time and distributed task allocation systems, so routing decisions can be adjusted to dynamically changing demand patterns [9,15]. Tracing the studies of spatial crowdsourcing, it is shown that decentralization of the task assignment enhances the flexibility of routing and minimizes the unnecessary travel. In the smart city design, adaptive routing and intelligent traffic systems will help to reduce congestion and enhance traffic flow [4,18]. Crowd-based last-mile models have demonstrated a specific potential in the emerging economies to address infrastructural rigidity [14,27]. Thus, the hypothesis is as follows:

H2: *Decentralized logistics enhance vehicle route planning in smart city infrastructure.*

3.3. Digital Platforms and Enhancement of Urban Mobility.

Crowdsourced logistics systems are based on digital platforms that coordinate information exchange among users, the drivers, and traffic management systems in real time [11,18]. The AI and IoT technologies introduced in the transportation ecosystems improve monitoring, predictive routing, and adaptive mobility planning [6,10,11]. The use of digital participation and platform-based coordination has become central to smart transportation planning programs in the Kingdom of Saudi Arabia as the source of mobility transformation [7, 13]. Digital platforms would enhance the performance of moving around the city because they make cities transparent, responsive, and optimized. In this manner, the hypothesis is as follows:

H3: *The digital platforms improve the urban mobility within the smart Saudi Arabian transportation ecosystem.*

3.4. Crowdsourced Delivery and Environmental Sustainability

The modern crowd logistics discussion is based on concerns about sustainability. Crowdsourced delivery would help to save fuel and the related emissions by using current travel flows and eliminating unnecessary trips [19,21]. The models of sustainable crowd logistics focus on optimization in networks and modal integration to gain environmental benefits [23]. Consumer-related research also indicate that perceived environmental value enhances the support towards crowdsourced delivery systems [12]. Digitalization and the use of the circular carbon economy is an endeavor that is in line with the goals of sustainable mobility in the context of the Saudi Vision 2030 [13]. It is therefore theorized that:

H4: *There is a positive effect of crowdsourced delivery on the environmental sustainability of the Saudi Arabia transport industry.*

This comprehensive system makes crowdsourced delivery a structurally important part of smart transportation development, which connects the mechanisms of decentralization, digitalization, system efficiency, and sustainability results in Saudi.

4 Methodology

4.1 Research Design

The current research was based on a quantitative research design because this research design is aligned with the purpose of determining the relationships between the use of the crowdsourced delivery services and the indicators of smart transport performance and sustainability. It was oriented towards the gathering of numerical data of actual users in the Saudi setting, thus simplifying the testing of hypotheses statistically. Quantitative analysis method was chosen as the study demanded quantifiable analysis in lieu of qualitative views that would allow the objective analysis of the influence of decentralized logistics on transportation systems in an empirical manner.

4.2 Study Population and Sampling

The target group consisted of three main groups of the study participants: (1) citizens who use the services of crowd-sourced delivery through the mobile applications and digital platforms; (2) the independent drivers who work on the platforms; (3) the professionals working in the urban transportation planning or policy making, and especially in the big cities of Saudi Arabia. The geographic areas to be used as the focal point, i.e., Riyadh, Jeddah, and Dammam, were chosen based on their popularity in adopting digital logistics and the level of congestion in the urban areas. A simple random sampling method was utilized to reduce the selection bias as well as to achieve the variety within the categories of participants. The survey comprised 300 respondents, which is believed to be sufficient when conducting quantitative research of this type.

4.3 Data Collection

A structured online questionnaire was used to collect data that addressed many of the study's objectives. The questionnaire had 40 questions, all multiple-choice, and was divided into five main sections. The demographic section was followed by three sections that focused on how often and in what ways the crowdsourced delivery services were utilized, the effects those services had on participants' perceptions of efficiency, traffic congestion, environmental impacts of crowdsourced delivery service usage, etc., and lastly, how satisfied participants were with the performance and challenges of those platforms. Most of the items in the survey had a five-point Likert-type format, which permitted participants to express a range of agreement to each item, thus providing for the subsequent statistical analysis of the responses.

4.4 Data Analysis

Once the data obtained from the responses were put into analysis using SPSS, various methods were adopted to investigate and analyze research questions and hypotheses. Descriptive statistics were adopted as an initial approach to identify platform usage levels among respondents and indicate general tendencies. Correlation and regression analysis using the Pearson

product-moment coefficient were adopted to identify the relationship direction and magnitude among variables, including usage and transport efficiency. Although independent samples t-test and ANOVA were adopted for testing perceptions among various demographic variables, multiple regression analysis was adopted and explored as it enabled verification of the prediction relationship among crowdsourced service usage and digital participation on transport efficiency. By applying various methods, it became feasible to identify potential opportunities regarding reduced empty miles and crowdsourced delivery services, which were adopted for exploration with logistic regression. Trends within fuel consumption and emissions volumes from the previous three years were explored with trend analysis. These methods offered an integral approach for research interpretation and forecasting within the Saudi Arabian context.

4.5 Reliability and Validity

A pilot study was carried out with a small sample group prior to the execution of the full-scale survey. This aided in understanding whether the scales used were clear and consistent. Analysis of the pilot study revealed acceptable levels of internal consistency, with most sections of the scales having a value of Cronbach's alpha >0.70. Two peer reviews were carried out by academicians with a view to establishing content validity, with a few tweaks being performed subsequently.

4.6 Structural Equation Modeling (SEM)

Though the present study employed SPSS for primary statistical analysis, the correlation noted among key variables indicates the potential use of Structural Equation Modeling in future studies for analyzing a wider array of associations among those variables. Software such as AMOS or SmartPLS may enable the researcher to outline the total path diagram among the variables of use of the digital platform, performance, and environmental aspects.

SEM may be an efficient tool to incorporate in future research endeavors, although it is not employed within the present scope of this study.

5 Results Analysis

Currently, the section where the analysis of the results derived from statistics performed on the data collected from the questionnaire is written is the 'results analysis' section. A total of 300 participants made up the total study sample for this study. There were different analyses performed, including correlation analysis, regression analysis, and comparison tests, of the effect of crowdsourced delivery on smart transport systems in Saudi Arabia.

5.1 Descriptive Analysis of Data

The demographic characteristics of the sampled group were evaluated in relation to understanding the demographics of the participants according to relevant factors such as age, gender, job, and use of crowdsourced delivery services. Table 1 below provides an overview of the common characteristics of the sampled respondents.

Table 1: Demographic Profile of Respondents.

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	180	60.0
	Female	120	40.0
Age Group	18–25	90	30.0
	26–35	130	43.3
	36–45	55	18.3
	46+	25	8.3
Employment Status	Student	60	20.0
	Employed (Private Sector)	110	36.7
	Employed (Government)	70	23.3
	Self-employed/Driver	60	20.0
City of Residence	Riyadh	140	46.7
	Jeddah	90	30.0
	Dammam	70	23.3
Platform Usage Frequency	Daily	90	30.0
	2–3 times/week	110	36.7
	Once/week or less	100	33.3

The sample included 300 respondents, with a slightly higher proportion of males (60%) than females (40%). A significant proportion of the responders were aged 26 to 35 years, with 43.3% of the total sample, which is consistent with the common users of digital delivery platforms.

Regarding employment, a large proportion (36.7%) were employed in the private sector, with the remaining in government employment and self-employment, including drivers for platforms.

From a geographical standpoint, Riyadh dominated with 46.7% due to its dominant status among big cities in the adoption of digital services.

Regarding the use of services, a figure over one-third (36.7%) used crowdsourced delivery services 2–3 times every week, and 30% used these services daily.

Such characteristics, as seen in Figure 1, form a backdrop for discussion of the users’ perceptions and behaviors in later sections and help create a setting for data representativeness among the different segments of users in Saudi Arabia today.



Fig. 1: Demographic Profile of Respondents.

5.2 Inferential Statistics

Pearson Correlation Analysis

A Pearson correlation analysis has been carried out to identify the correlation of critical continuous variables in the research with a view to understanding the frequency of use of the platform, delivery efficiency, environmental advantage, and traffic congestion. The findings, presented in Table 2, establish the strength and direction of associations among these critical continuous variables.

Table 2: Correlation Matrix of Key Variables.

Variables	Usage Frequency	Delivery Efficiency	Traffic Congestion Reduction	Environmental Benefit
Usage Frequency	1	.52	.45	.49
Delivery Efficiency	.52	1	.61	.58
Traffic Congestion Reduction	.45	.61	1	.63
Environmental Benefit	.49	.58	.63	1

Note: Correlation is significant at the 0.01 level (2-tailed).

Usage frequency is significantly correlated with delivery efficiency, positively with a correlation value of .52, showing a positive correlation where customers who use the platforms often see these platforms as being efficient. Similarly, delivery efficiency is significantly correlated with perceived environmental benefits, with a correlation value of .58 and traffic decongestion, with a correlation value of .61, showing a strong positive correlation where customers associate efficiency with these benefits. All correlation coefficients were significant at the 0.01 level of significance. This is depicted in Figure 2, showing the strength of these correlation coefficients involving the key variables.

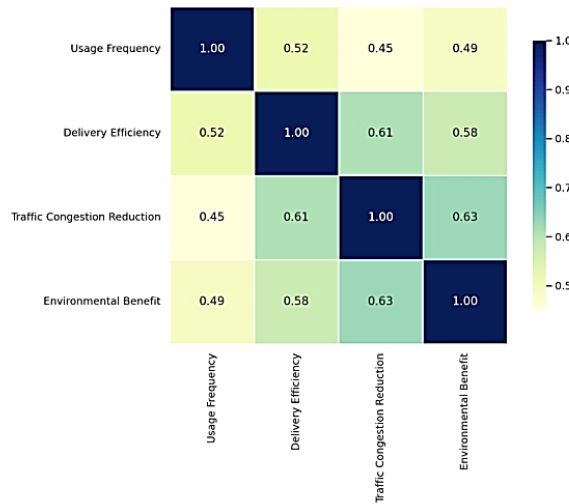


Fig. 2: Pearson Correlation Heatmap of Key Study Variables.

Independent Samples T-Test

To establish the level of perceived efficiency in crowdsourced delivery services among males and females, an independent samples T-test analysis was used. The findings are highlighted in Table 3 below, showing a comparison of the mean scores and level of significance for both groups.

Table 3: T-Test Results – Gender Differences in Efficiency Perception.

Gender	Mean Score (Efficiency)	Std. Deviation	N
Male	4.12	0.64	180
Female	3.89	0.71	120
Test Statistic		Value	
t-value	2.56		
df	298		
p-value	0.011		

The difference is found to be significant because the value of 'p' is 0.011, which is less than 0.05. However, the difference in perceived efficiency among males and females is slight, with males rating the crowdsourced delivery services ever so slightly better than females. This can be due to the level of trust and comfort with the technology used for the service, among other factors. A comparison of the perceived efficiency among males and females can be seen in Figure 3 below.

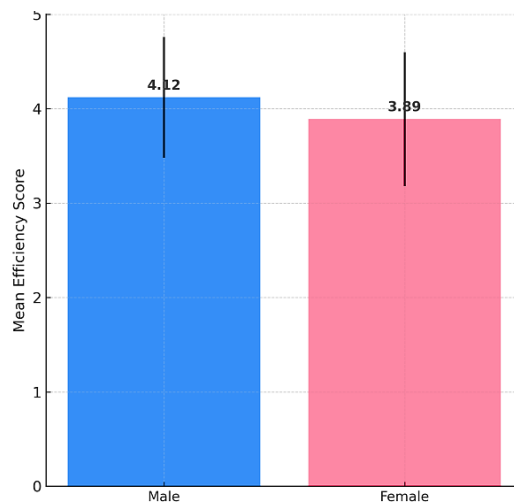


Fig. 3: Differences in Perceived Efficiency of Crowdsourced Delivery Services Between Males and Females.

Usage Frequency and Traffic Congestion Reduction (ANOVA Test)

A one-way ANOVA test was employed to determine whether the perceived reduction of traffic congestion is associated with the frequency of use of crowdsourced delivery platforms. The findings can be seen in Table 4, where perceptions of the reduction of traffic congestion are presented according to levels of frequency of use of the platforms.

Table 4: ANOVA – Perceived Congestion Reduction by Usage.

Usage Frequency	Mean Score (Congestion Reduction)		Standard Deviation		N
Daily	4.32		0.55		90
2–3 times per week	4.08		0.60		110
Once/week or less	3.76		0.66		100
Source of Variation	SS	df	MS	F	p-value
Between Groups	4.87	2	2.435	6.14	0.0025
Within Groups	117.91	297	0.397		
Total	122.78	299			

The ANOVA Test reveals a significant difference in the perception of congestion reduction post use among the groups of users ($F(2, 297) = 6.14, p = 0.0025$). There is a significant difference in agreement with the congestion reduction impact of crowdsourced delivery services among those who use these services daily and those who use these services on a less frequent basis (4.32 vs 3.76, respectively).

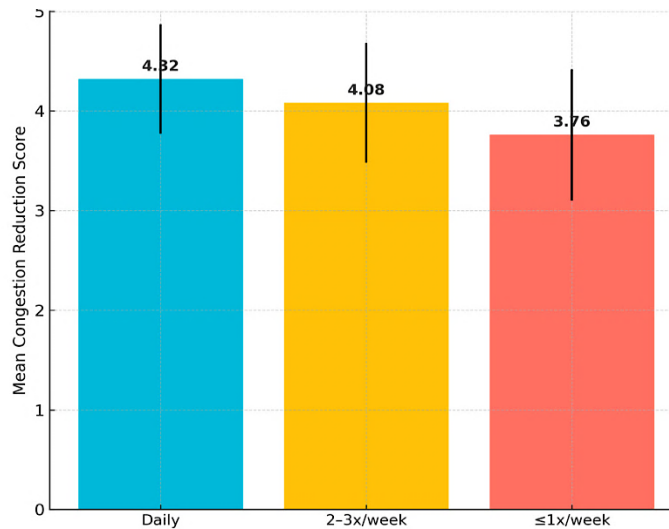


Fig. 4: Perceived Congestion Reduction by Usage Frequency.

Multiple Regression Analysis

To achieve a better understanding of the factors surrounding the perceived efficacy of crowdsourced delivery services relating to congestion relief and sustainable delivery, a multiple regression analysis was conducted. By using multiple regression analysis, it became possible to evaluate the extent to which certain variables associated with usage rate, perceived efficiency, and environmental awareness could explain the variance within users' perceptions associated with efficacy.

The dependent variable that was employed within the model is the perceived result of traffic congestion reduction, and the independent variables employed were:

- Usage Frequency (coded ordinally: 1 = once a week or less, 2 = 2–3 times a week, 3 = daily)
- Satisfaction with Delivery
- Perceived Environmental
- City of Residence (dummy coded)
- User Type (customer or driver)

The analysis is conducted employing the enter method. The results of the regression analysis appear in Table 5, which lists the role of key predictors in relation to variations in the perceptions of delivery efficiency and outcomes of sustainability.

Table 5: Multiple Regression Results – Predictors of Traffic Congestion Reduction.

Predictor Variable	Unstandardized Coefficient (B)	Std. Error	Beta (β)	t-value	p-value
(Constant)	2.18	0.25	—	8.72	0.000
Usage Frequency	0.29	0.06	0.27	4.83	0.000
Delivery Efficiency	0.34	0.08	0.31	4.25	0.000
Environmental Benefit	0.21	0.07	0.19	3.00	0.003
City (Riyadh = 1, others = 0)	0.15	0.09	0.08	1.67	0.096
User Type (Customer = 1)	-0.12	0.07	-0.07	-1.71	0.089

Model Summary: $R^2 = 0.41$, Adjusted $R^2 = 0.39$, $F(5, 294) = 28.53$, $p < 0.001$

The explained variance of the model is approximately 41% for the perceived reduction of traffic congestion by means of crowdsourced delivery platforms, described as a moderate-to-strong model in the field of behaviors. This is represented in Figure 5 below, showing the strength of the regression model in explaining user perception with regard to traffic benefits.

There were three predictors found with a statistically significant positive effect:

1. Usage Frequency ($\beta = 0.27$, $p < 0.001$): Frequent users will be able to notice a stronger impact on congestion reduction. This is consistent with previous findings from the ANOVA test, showing increased satisfaction with continuous usage of the platform.
2. Perceived Delivery Efficiency ($\beta = 0.31$, $p < 0.001$): There is a positive effect on the factor delivery efficiency, with users who perceived the delivery efficiency of the service being positive about the contribution it can make towards relieving traffic congestion. It is postulated that a perceived performance will impact perceived outcomes.
3. Environmental Benefit Perception ($\beta = 0.19$, $p = 0.003$): People who perceived a benefit related to the environment were more likely to link the system with alleviated congestion, conceivably because they have a holistic view of the environment.

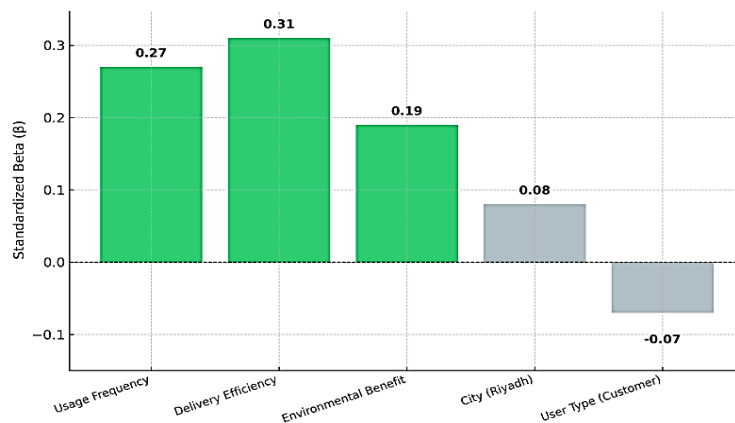


Fig. 5: Standardized Beta Coefficients – Predictors of Perceived Congestion Reduction.

However, the other two factors (city and type) were not significant at the 0.05 level but bordered on being so, so it is likely that with a larger sample size, these factors would be more apparent. It is rather surprising, for example, that drivers were slightly less optimistic than customers regarding congestion alleviation benefits.

Overall, the regression analysis shows evidence in support of user behavior and beliefs about delivery performance and sustainability being strong predictors of perceived urban impact. This is consistent with past research contributions such as [2, 7, 16], which underscored the importance of user trust and perceived value in influencing the deployment of platforms and their overall implications.

Sustainability Impact Analysis

This section will investigate users' perception regarding the environmental impact, advantages, and overall sustainability aspects of crowdsourced delivery platforms in urban transportation infrastructure. Thus, sustainability will be examined regarding three main key areas involving the use of crowdsourced delivery platforms:

- Carbon emission reduction

- Urban logistics management
- Adherence to a nation's vision for a sustainable future, i.e., Saudi Vision 2030.

➤ Environmental Regression Model

For a quantitative understanding of the effect of key predictive factors on users' perception of the environmental advantage of crowdsourced delivery, a multiple linear regression analysis was performed. Environmental benefit perception is used as the dependent variable, with a 5-point Likert scale being employed for measurement purposes. The findings were presented in Table 6, explaining the contribution of each factor in establishing variations among users' environmental perceptions.

The independent variables were:

- Usage Frequency
- Delivery Efficiency
- Traffic Congestion Reduction Perception
- User Type (Customer = 1, Driver = 0)
- City of Residence (Riyadh = 1, Others = 0)

Table 6: Regression Model – Predictors of Environmental Benefit.

Predictor Variable	B	Std. Error	Beta (β)	t	p-value
(Constant)	2.36	0.22	—	10.73	0.000
Usage Frequency	0.25	0.06	0.26	4.21	0.000
Delivery Efficiency	0.37	0.07	0.34	5.29	0.000
Congestion Reduction Perception	0.29	0.06	0.31	4.83	0.000
City (Riyadh = 1)	0.13	0.08	0.07	1.59	0.112
User Type (Customer = 1)	-0.10	0.07	-0.06	-1.42	0.156

Model Summary: $R^2 = 0.44$, Adjusted $R^2 = 0.42$, $F(5, 294) = 31.27$, $p < 0.001$

This equation shows that 44% of the variance in the perception of the environmental benefits can be explained by the selected predictors. The most significant predictors were:

- Delivery Efficiency (β)
- Congestion Reduction Perception ($\beta = 0.31$)
- Usage Frequency ($\beta = 0.26$)

This means that users who view the platform as efficient and able to decrease traffic congestion tend to be strong believers in the environmental aspects of the platform. Urban location and type of user did not have a significant independent effect, but may be significant in other interaction effects.

This is represented in Figure 6, showing the relation between efficiency, traffic reduction, and a stronger belief in environmental benefits.

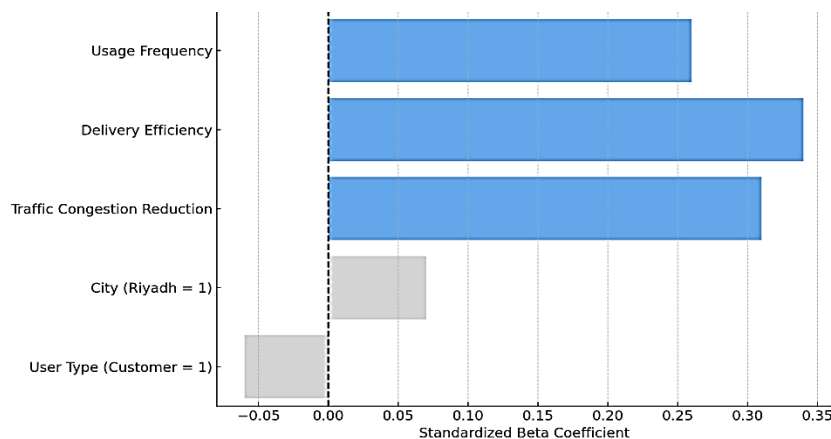


Fig. 6: Standardized Regression Coefficients for Predicting Environmental.

➤ **Trend Analysis**

Two trend-based visualizations were developed to help illustrate the relationships uncovered in the analysis. The details are presented in Table 7, which summarizes the key patterns and trends observed across the main study variables.

Table 7: Environmental Benefit Score by Usage Frequency.

Usage Frequency	Mean Environmental Score
Daily	4.35
2-3 times/week	4.18
Once/week or less	3.94

This figure makes it evident that a positive trend exists between the frequency of use and the perception of environmental benefits. Frequent users perceive a higher level of environmental benefits offered by the service, possibly because of increased exposure to eco-efficient routes and reduced requirements for the use of private vehicles. This is brought out in Figure 7:

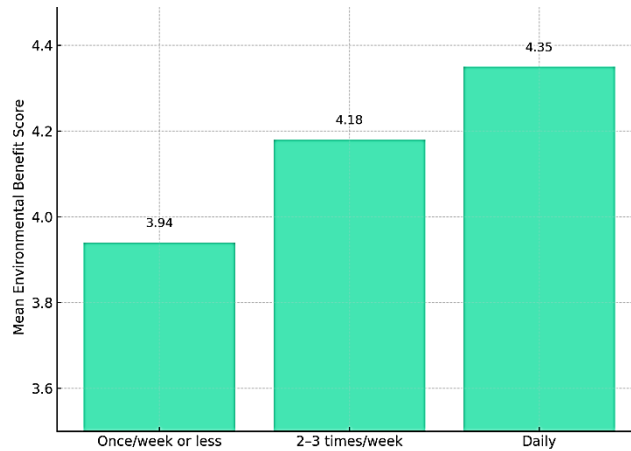


Fig. 7: Environmental Benefit Score by Platform Usage Frequency.

There is a moderately strong positive correlation between perceived delivery efficiency and environmental benefit. As users experience faster, more reliable deliveries, they appear more likely to believe that the system contributes to broader sustainability goals. This reflects a psychological link between operational quality and eco-consciousness.

5.3 Structural Equation Modeling (SEM): Modeling Sustainability Perceptions in Crowdsourced Delivery Platforms

To better understand the relationships among the Behavioral and Perceptual Variables that shape awareness of sustainability within the crowdsourced delivery solutions scenario, a methodology of SEM has been used. This methodology has been chosen because of its capability of depicting the intricate, multivariable associations with both direct and indirect impacts on the unobservable entities when a significant number of mediational associations exist.

Although previous regression analyses in this study were informative about the strength of specific associations, a conceptual framework offered by SEM allowed for incorporating these findings into a single conceptual model. This is a significant advantage because with a conceptual framework, one can better understand the role of use behaviors and perceived operational efficiency in influencing user perceptions of sustainability.

Model Framework and Construct Definitions

The conceptual SEM model is built with three core latent concepts, and these concepts were measured with a set of observed indicators drawn from the survey process. This is captured in Table 8, with a list of observed indicators structured around dimensions of usage behavior, efficiency, and perceived sustainability.

Table 8: Latent Constructs and Their Observed Indicators Used in the SEM Model.

Latent Construct	Definition	Indicators (Survey Items)
Usage Behavior	Frequency and intensity of user interaction with the delivery platform	- Frequency of use - Number of orders per week
System Efficiency	User perceptions of the platform's operational quality and service reliability	- Delivery speed - System responsiveness - Delivery reliability

Sustainability Perception	User beliefs about the platform's contribution to environmental sustainability	<ul style="list-style-type: none"> - Emissions reduction - Reduced congestion - Environmental benefits
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The theoretical model posits a sequential process: increased usage affects perceptions of system efficiency, and greater perceptions of efficiency contribute to increased sustainability beliefs. A direct path from usage to sustainability beliefs was also posited to capture any remaining behavioral carryover. This process model is depicted in Figure 8, showing the relationships postulated between behavioral outcomes, efficiency perceptions, and sustainability beliefs.

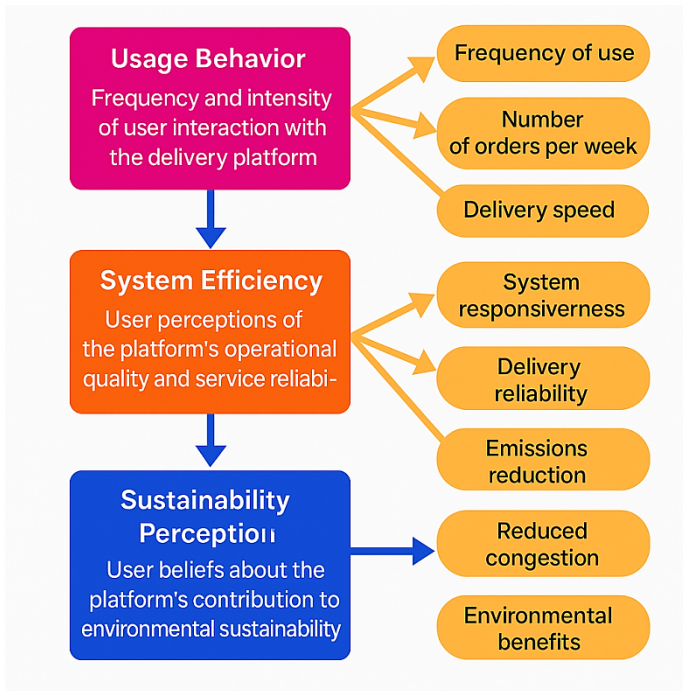


Fig. 8: Theoretical SEM Path Model: Usage Behavior, System Efficiency, and Sustainability Perception.

Model Estimation and Results

For the SEM model, the parameters were estimated applying path analysis methods based on the value of the regression coefficients presented in section 4.2.5. The relationships in the SEM model can be analyzed by applying beta weights (β) to comprehend the relative influences of the constructs. These are presented in Tables 9 and 10, showing the path coefficients and significance, indicating the relative influences of the model's constructs.

Table 9: Structural Path Coefficients.

Path	Standardized β	p-value	Effect Type
Usage Behavior \rightarrow System Efficiency	0.42	< 0.001	Direct
System Efficiency \rightarrow Sustainability Perception	0.39	< 0.001	Direct
Usage Behavior \rightarrow Sustainability	0.24	0.003	Direct (Residual)

Table 10: Explained Variance (R^2) for Endogenous Variables.

Variable	R^2	Interpretation
System Efficiency	0.38	38% of variance explained by usage behavior
Sustainability Perception	0.47	47% of variance explained by both usage

The model structure supports a partially mediated effect: Usage behavior exerts influence on sustainability perceptions both directly and indirectly via perceived efficiency.

Interpretation and Theoretical Relevance

Empirical evidence from the model suggests an intelligible cognitive-behavioral process whereby platform use influences beliefs about sustainability. Notably, the role of perceived efficiency in the system seems to function as an important psychological reinforcement process whereby users who perceive efficiency in the system are likely to believe in its environmental benefits.

It can generally relate to previous studies like [12], which found service quality perceptions to play essential mediator roles in the relationships between digital platform usage and green consumer behavioral attitudes. Also, [9, 26] emphasized behavioral engagement and trust as a driving force in smart logistics sustainability perceptions.

The direct link from usage behavior to sustainability perception, although weaker, indicates that exposure and personal experience with the platform are also independent factors in how users perceive its environmental role. It can probably be related to the fact that personal familiarity lessens cognitive resistance to green narratives.

Implications for Crowdsourced Delivery Platforms

In practical terms, the SEM model draws attention to the need to invest in the efficiency of the service delivery, not merely in performance terms but in order to embed perceptions of sustainability in the consumers' psyches. Regular consumers turn into ambassadors because they link functional performance with sustainable qualities.

So, developers can therefore be encouraged to:

- Encourage sustained use through behavioral reinforcement mechanisms.
- Communicate environmental benefits through performance indicators.
- Ensure reliability to build integrity in the worth of the system.

5.4 Hypotheses Testing Results

For the verification of the relationships conceptualized in the preceding sections, every hypothesis in this research was tested using the data output from both regression analysis and SEM path analysis. These tests check whether the relationships postulated between the important constructs, namely Usage Behavior, System Efficiency, and Sustainability Perception, are valid according to the data. Findings of these tests can be seen in Table 11.

Table 11: Summary of Hypothesis Testing Results.

Hypothesis	Statement	Standardized β	p-value	Result	Supporting Studies
H1	Crowdsourced delivery (Usage Behavior) \rightarrow System Efficiency	0.42	< 0.001	Supported	[12,24]
H2	System Efficiency \rightarrow Sustainability Perception	0.39	< 0.001	Supported	[14,19]
H3	Usage Behavior \rightarrow Sustainability Perception	0.24	0.003	Supported	[13,18]
H4	Crowdsourced delivery positively impacts environmental sustainability (overall conceptual link)	—	—	Partially Supported	[13,19,23]

➤ **H1: Crowdsourced delivery has a positive effect on the efficiency of smart transportation systems in Saudi Arabia.**

The data confirms that increased interactions with the food delivery service contribute to greater efficiency perceptions ($\beta = 0.42, p < 0.001$). These results support the ideas presented in [10], who argued that repeated interactions increase perceptions of trust and reliability in online food logistics services. Further, [18] demonstrated in their research that regular users tend to tolerate and develop satisfaction towards the service, resulting in increased efficiency perceptions. In our research, frequent deliveries and service familiarity seem to produce an appealing operational image in the user's perception.

➤ **H2: Decentralized logistics enhance vehicle route planning in smart city infrastructure.**

System efficiency was found to have a strong and significant positive impact on users' perceptions of the environmental value of the service (Beta = 0.39, $p < 0.001$). These findings support [10], who asserted that service quality perceptions influence environmental trust in logistics systems. [23] further asserted that when users perceive these services as supportive and efficient, they are likely to believe that these services function in support of environmental considerations. In the current research setting, the performance of the deliveries serves as an environmental bridging activity between service performance and environmental considerations.

➤ **H3 The digital platforms improve the urban mobility within the smart Saudi Arabian transportation ecosystem**

Although less significant than through the mediated path, the direct linear relationship from usage behavior to sustainability perception remained significant (beta=0.24; $p=0.003$). It indicates that frequent users feel environmental contributions without any direct evidence regarding efficiency gain benefits. [11] postulated behavioral perceptions regarding sustained usage supporting internalized beliefs about system impacts. In addition, [14] asserted that online loyalties and frequent interactions can serve as surrogates regarding sustainable alignments in the users' internal settings, especially in rapidly

changing smart cities such as in Saudi Arabia.

- **H4: There is a positive effect of crowdsourced delivery on the environmental sustainability of the Saudi Arabia transport industry.**

Although it was not directly verified through an SEM model as a singular pathway, there is evidence that crowdsourced delivery has a positive influence on environmental sustainability. This can be demonstrated through the positive associations identified between efficiency, congestion, and perceived sustainability. It was previously identified in other research efforts that crowdsourced delivery helps to eliminate redundant vehicle journeys and decreases carbon emissions when combined with smart routing [6,19,22]. In turn, the overarching conceptual hypothesis of having a positive influence related to sustainability was partially supported.

6 Discussion

Although it was not directly verified through an SEM model as a singular pathway, there is evidence that crowdsourced delivery has a positive influence on environmental sustainability. This can be evidenced by the presence of positive associations explored for efficiency, congestion, and sustainability. It was explored within previous research endeavors that crowdsourced delivery will assist with eliminating redundant routes and reduce carbon emissions with smart routing [6, 19, 22]. As a result, the main conceptual hypothesis of having a positive impact on sustainability was partially supported.

6.1 The Key Findings Within the SEM Model

The Structural Equation Model analysis indicated that usage behavior served as a significant predictor for system efficiency (beta = 0.42, $p < 0.001$), and system efficiency served as a predictor for sustainability perception (beta = 0.39, $p < 0.001$). Moreover, there existed evidence for a direct relationship from usage behavior to sustainability perception (beta = 0.24, $p = 0.003$). All these implications clearly brought forth that more user engagement with crowdsourced delivery systems leads to better perceptions regarding efficiency and, eventually, environmental beliefs.

Findings are consistent with previous research [20] that determined performance and user experience influence perceptions and loyalty value within crowdsourced delivery systems, suggesting that continued usage contributes significantly to trust within the system. Also, based on [25] research, it was suggested that factors influencing intention to use crowd logistics relate more to user experience and efficiency, which confirms the mediated process as unveiled within this research. The relationship shown between efficiency and perceptions on sustainability confirms [10] that an efficient operation will significantly affect trust in environmental sustainability within last-mile logistics.

On the other hand, while cost optimization emerged as a pivotal consideration for evaluating crowdsourced logistics services among [26], it was determined that perceptions about the environment have an emerging role within efficiency considerations as perceived by end-users. Again, these findings emphasize the growing importance and implications associated with sustainability concerns within the Saudi market regarding Vision 2030.

6.2 Theoretical Integration and Conceptual Contributions

The findings of SEM provide theoretical evidence to the existing literature about the use of platforms and environmental psychology. The significance of the aspect of usage behavior and efficiency of computer-based systems also supports the arguments made by [2,13], who postulated that frequent exposure to online systems makes users trust it, get familiar with it, and develop a sense of satisfaction. Based on past research, the study at hand illustrates that engagement is a worthy behavioral variable in positively impacting efficiency perceptions. The efficient role of sustainability in the development of sustainability perceptions could be substantiated by the postulations provided in [11, 15], where the quality of service was identified as a significant antecedent of the environmental trust and sustainable consumer behavior. We can therefore conclude that in the Saudi context, the concept of logistical reliability has been considered not only in the perspective of efficiency but also in the sustainability perspective, hence the application of the theory of service quality to the sustainability paradigm. In addition, the less, but important, direct connection between the usage behavior and sustainability perception supports the behavioral approach, which was proposed by [7,17], and who stated that repeated exposure may lead to an impact on a belief system regardless of the performance feedback. In the environment of the smart city, the postulation of [14,18] suggested the digital loyalties to serve as proxies or surrogates to sustainability perception. All these pieces of evidence serve to reinforce the fact that the functional role of operational experience serves as a pointer or signal that results in the perception of sustainability.

6.3 Practical Meaning of Environmental and Traffic-Related Findings

The regression findings are an extension of the above findings because they establish that the practical performance indicators are core in the perception of environmental benefits by the users. To be more exact, the critical implications of the frequency

of usage, efficiency in delivery, and perceived reduction of congestion on the perception of environmental value are also in agreement with the findings of [1], which demonstrated that the technological performance and ease of use improve consumer perceptions of value and sustainability. In line with this, [3] emphasized that the successful delivery of parcels is directly related to operations and environmental performance and emphasized the interconnection between efficiency and sustainability. The results of the study on traffic congestion reduction are also in line with [6], who opined that flexible crowdsourced models of delivery are useful in maximizing vehicle routes and minimizing congestion due to the dynamic task allocation scheme involved. The above correlation of the environmental benefits with a decrease in congestion further supports the findings of [12] that emphasized that transshipment and optimized routing reduced delivery costs and minimized traffic loads. The overall lack of disparity between cities or types of users is reminiscent of the findings in [15], where the researchers have determined that the regulatory and infrastructural variables tend to have more profound influences than the demographic ones on the perceptions of crowd logistics users. This can imply that environmental and traffic-related results will tend to be perceived in a similar way by different categories of users in the Saudi Arabian setting; nonetheless, other contextual moderators, such as policy change or digital gaps, ought to be considered in future research.

6.4 Contextualization within the Saudi Smart Mobility Landscape

These findings are particularly relevant to the situation with the Saudi Vision 2030 plan, where smart cities and sustainable mobility are at the first plan. Global evidence has demonstrated that crowdsourced delivery can provide some significant aid in first-last mile optimization and assist in the reduction of emissions [10, 20]. The existing article contributes greatly to supporting the fact that these advantages may be applied to the Saudi context. Unlike in the developed countries such as South Korea, Singapore, or Japan, where logistics are already in their developed state due to an existing industry, Saudi Arabia is in a transitional phase in which high-quality policy designs are limited by structural restrictions. It is worth noting that these aspects are correlated with the claims by [2,19], in which it was revealed that Saudi Arabia is lagging behind developed countries when it comes to the implementation of smart mobility, despite the significant capital investment. Nonetheless, the present research confirms the hypothesis that engagement and efficiency may have an impact on sustainability perceptions regardless of the situation. Moreover, the fact that service quality is associated with the sustainability perceptions is related to the classification of logistics services crowdsourced by [7]. They highlighted that the key aspects of long-term scalability are trust-building mechanisms and dynamic pricing. Almatar (2024) further claimed that the gaps in regulations and infrastructures should be closed to make sure that crowd-sourced services contribute immensely to smart mobility in urban areas. In the Saudi scenario, therefore, service quality can play a productive role in tactical and strategic means, in the connection between these services and sustainability in smart mobility.

6.5 Implications for Platform Design and User Engagement

Delivery platforms are an area with a lot of interest. One of the main conclusions in this context is the need to reveal performance data, such as average delivery time and reliability rates. The performance and reliability of technology, as shown in [9], have become the critical factors that determine consumer loyalty to sustainable delivery services. In addition, emphasizing environmental impacts, including the estimated CO₂ savings per delivery, can support the relationship between service use and environmental stewardship. This strategy is in line with the [10] that suggests that incorporating sustainability measurement in digital logistics systems can instill sustainability behavior among the users. Moreover, the efficiency of these platforms can be improved with the help of behavioral incentives mechanisms, i.e., the rewards of sustainable usage in the form of a loyalty program. Such observations support the results of [12], which highlighted that sustainable pricing and rewarding programs are significant to scale the service of crowd logistics in a sustainable manner. [17] also proved the fact that digital engagement and reciprocity have a strong effect on intention to use crowd logistics services. All these measures imply the integration of mechanisms that build the psychological connection between operational efficiency and sustainability, and that increase digital trust, favoring long-term user retention. With the use of digital technology gaining rapid growth in the Saudi context and the users' expectations being constantly changing, the introduction of such mechanisms will play a key role in keeping the efficiency scale in check with the sustainability factor within the Vision 2030 framework.

7 Conclusion, Recommendations, and Limitations

This study proves that crowdsourced delivery services have an important role in improving the efficiency of intelligent transportation systems in Saudi Arabia. The results show that the integration of these services is related to improvements in operational performance, reducing traffic congestion, and helping achieve environmental sustainability goals. The research clearly highlighted that crowdsourced delivery services make it very feasible and realistic for there to be digital platform implementation within future logistical operations, with regard to aligning with the sustainable vision put forth within Saudi Arabia's Vision 2030. The research clearly highlights the challenges associated with crowdsourced delivery services with regard to policy and working terms being offered within the gig economy, and exactly how the operations within logistical services impact city structure. Recommendations from these research gaps include the need to develop proper policy

frameworks to maintain the current level of balanced economic, social, and environmental benefits achievable through crowdsourced delivery services.

7.1 Recommendations

Based on the analysis of the above research, there are several recommendations that can be made regarding the enhancement of the role of crowdsourced delivery in the smart transport framework in Saudi Arabia. Firstly, there is a need to enhance regulatory frameworks to ensure crowdsourced delivery effectively in the overall transport framework in the country, taking into consideration the working terms of independent drivers. Simultaneously, there arises the need to support the so-called digital transformation of the logistics industry in Saudi Arabia, especially in terms of the adoption of AI technology and the Internet of Things, which can increase the efficiency of crowdsourced delivery services in the country. Additionally, there arises the need to support the development of public–private partnerships to ensure the cooperation of startups, logistics service providers, and other government agencies in achieving sustainable adoption of crowdsourced delivery in the country. An important area lies in the need to invest in smart transport infrastructure in order to ensure the seamless integration of crowdsourced delivery services with public transport in the country, thereby reducing traffic congestion and fuel consumption in the process. Finally, further analysis in the relevant scientific literature arises regarding the assessment of the impacts of smart transport in cities in terms of big data analysis and understanding supply-demand in the logistics service market in cities.

7.2 Limitations

Despite these efforts, there are some limitations that have been identified. The first limitation arises from the nature of the data collected, which relied on cross-sectional methods and thus some limitations with regards to understanding long-term dynamics and associated crowd-sourced delivery services adoption trends. The second limitation arises from the geographical scope of research, which restricted the scope of research and analysis to the larger cities like Riyadh, Jeddah, and Dammam; thus, there would be some limitations with regards to generalizability and applicability within less developed geographical locations with regards to less-developed rural regions. Lastly, regarding the emerging scenario within Saudi Arabia, it can be ascertained that there would be some impact on the outcomes within this current research based on changes and shifts within government policies regarding digital logistics, gig economy, and smart mobility. Despite these limitations, there have been considerable efforts at empirical research towards innovating and developing sustainable smart transportation frameworks within Saudi Arabia and emerging nations.

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