

Zipline: Life-saving drone service Re-defining the Supply Chain

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Abstract- The study investigates the disruptive nature of the application of drone logistics by Zipline to traditional supply-chain practices, and aims to discuss more general implications in the healthcare setting, in particular, Ghana and the health system of Rwanda. The key findings of the study examine the effects of drone technology in reducing the cost of transport, supply chain interruption, and increasing resiliency and sustainability. The study utilized a mixed methodology and collected both quantitative and qualitative data of 200 stakeholders with the help of the structured questionnaires which were quantified in a social sciences statistical package (SPSS) to analyze the data. The results of the analyses indicate that the drone logistics cargo at Zipline lowered the delivery time, cost, and improved the efficiencies and enabled the delivery of healthcare resources in rural settings. The regression test showed a statistically significant correlation between the drone technology and sustainable supply chain and resilient supply chain, whereas there was moderation of factors due to both supply chain sustainability and resiliency when using drone technology. The study concludes with recommendations stemming from the evidence of disrupting conventional supply chain mechanisms using drone logistics capabilities to develop a more agile, accessible, equitable and sustainable logistics system for healthcare. Future research and studies should focus on the scalability and sustainability of drone logistics in relation to geographic and economic contexts.

Keywords: *Drone logistics, Zipline, Supply chain resilience, Healthcare delivery, Sustainability, Last-mile distribution*

I. INTRODUCTION

Zipline is a trailblazer in the concept of logistics and drone delivery. It specializes in the fully

autonomous, on-demand delivery of medical supplies and consumer products. Zipline was founded in 2014 in California to increase access to essential healthcare in rural and underserved populations (Nisingizwe et al., 2022) and used unmanned aerial vehicles (UAVs) for on-demand deliveries of blood, vaccines, and medicines to hard-to-reach hospitals and clinics in 2015 that quickly became a company to be watched as an innovative method of service. Using advanced drone technology, Zipline is able to ensure that the delivery of important medical supplies reaches the proper person at the proper time, thus reducing delivery times significantly (Peltier & Meledeu 2023).

In the very early stages, Zipline concentrated on supporting operations with delivery in Rwanda and Ghana, where it played a key part in supporting the strengthening of healthcare infrastructure through assurances of reliable and timely deliveries (Pfizer Inc 2021). These deliveries through Zipzone technologies operate from distribution centers, typically located near the area of demand to ensure a range of coverage that can be greater than 100 miles in minutes. Zipline can use fixed-wing drones that work in any weather and carry up to 1.8 kilograms (Zipline 2024). In order to drop packages, Zipline relies on a parachute-based system that simply and effectively enables exact drops in difficult and remote locations. The company has had a tremendous impact in these areas, ranging from reducing maternal mortality rates, improved vaccine distribution, and improved emergency response (Field 2024).

Zipline, the drone-based technology, has been created to respond to deficiencies with medical supply items specifically in developing countries, where there is limited or no infrastructure. Initially working with the government of Rwanda, they began with drops of blood products, which are limited due to shelf life during emergencies (Reach Alliance 2021). Utilizing drones to deliver medical supplies will decrease waste and create better utilization in healthcare, by getting these supplies with speediness and reliability. Zipline has transformed delivery of life-saving supplies in Rwanda and Ghana, providing reliable access to medical supplies, decreased waste, and trust in healthcare systems. Zipline has delivered thousands of blood units, vaccines and medical products impacting patient outcomes and improving efficiency in health care (Sharma 2024).

Zipline's system leads to modular and precisely dosed packaging so that the products are delivered safely, with waste being tied to a minimum. Furthermore, the operational viability of Zipline's real-time, on-demand delivery system is building a build-to-order logistics model for healthcare organizations and manufacturers (Atiga 2024). The organization does not manage inventory from a pre-production perspective, rather from a more lean and reactive-to-consumption model. In this way, overproduction and stockouts of medical/health products are reduced and think conformance to JIT and an agile supply chain (Chopra & Meindl, 2022). Manufacturers now must consider the demands of building products that are not only medically effective but meet the logistical demands of an airborne distribution model. In the short run, Zipline's service innovation has offered immediate advancements in health outcomes, particularly for rural areas. The facilities will have lower holding costs, less inventory, faster response to emergencies, etc. (Zipline Case, p. 4). This in turn creates product-level opportunities for prototype testing and specialty products as logistics is no longer a limitation for a more distained population. Zipline offers a cost-effective alternative for manufacturers and government, with per-flight targeted costs ranging from \$1 to \$10, competitive with, or better than its rural transport alternatives (Zipline Case, p. 6).

While the long-term implications could be even higher, as Zipline continues to grow, it could become an integral part of decentralized on-demand

health services responsible for driving access in low and middle-income countries and, eventually, developed markets; thus, democratizing access but enabling intelligent forecasting of data in which upstream partners can continually cross-cut demand-supply data and episodic patient population narratives (Reuters 2021). The increased acceptance of drone logistics is invariably leading to formal technology partnerships with pharma, public health, and logistics systems, paving the way for co-developed new products and packaging opportunities for reported products.

Zipline's service innovation subsumes implications for product development and demand generation across the healthcare supply chain. It enables leaner and more nimble production models and opens up access to necessary care for underserved populations (Bloomberg News 2021). Although short-term impacts focus on cost-savings and improved access, ultimately, the long-term impacts are about changing how products are designed, distributed, and consumed. For these longer-term developments to maximize value, it is necessary for manufacturers to work with Zipline on drone compatibility and for governments to create beneficial regulatory regimes that enhance systems' innovative capability (Sharma 2024).

1.1 Feasibility of Transitioning from Hub-and-Spoke to Milk Run Model

Zipline, a logistics firm that is using technology to fly drones powered by energy from time-sensitive medical supplies, operates using a hub-and-spoke distribution model whereby drones will fly a package from a central hub location to a health facility. With this distribution model, it can offer a high speed and point-to-point delivery model like courier services. In contrast, the "milk run" model is typically deployed by ground logistics industries; it involves a single vehicle or drone to make multiple deliveries along a route - for example, sequentially delivering packages to different health facilities. The milk run model can improve hauling efficiency along high-density routes, but presents substantial challenges on operational, technological and strategic levels from Zipline's current model and mission.

Zipline delivers medicines faster than any other manufacturer in the world, by utilizing the hub-and-spoke model. Using it, Zipline launches its delivery drones from a single central hub to deliver products

to one clinic or hospital at a time. This model allows Zipline to quickly ship products, with low routing complexity and a highly responsive delivery service. The hub-and-spoke model corresponds closely to Zipline's rural/time urgency use case cases in that it is great for emergencies and allows for real-time control of inventory. The milk run model is more cost-effective in circumstances with stable demand trajectories and demand in multiple locations in close geographic proximity (Chopra & Meindl, 2022).

Implementing a milk run model requires major changes to Zipline's existing operations. Zipline's drones are fixed-wing aircraft meant for single deliveries and cannot safely carry additional weight as they are functioning in updrafts or downdrafts when making aerial deliveries. Zipline's current drone delivery capabilities in this regard can carry about 1.8 kg (Zipline Case, p. 4). Their drone launches from a catapult and hooks are also not suitable for multiple landings or multiple landing spots during a single mission.

Zipline's core value proposition is based on speed, reliability, and service to remote, underserved areas who need on demand emergency supplies. This demonstrates the responsiveness of the service and value in emergency situations. The milk run model focuses on efficiency, and would be contradictory to the responsiveness by speed, when it comes to on-demand deliveries. For example, if a drone is delivered on a fixed multi drop path, an urgent delivery to one of the clinics could be delayed and would risk lives if it made stops to all scheduled facilities before, hence delayed delivery to this facility.

The purpose of this study is to examine how Zipline's innovative drone-based logistics system is transforming the traditional supply chain framework, particularly within the healthcare sectors of Rwanda and Ghana. The study will establish the manner and degree to which a drone technology will save money, introduce a significant supply chain imbalance, and add values in terms of resilience and sustainability. The study presents efficiency of operations in relation to Zipline drone delivery service, and strategic implications to give an insight into the variety of supply chain designs in which drone operations can offer speed, reliability, and reduced cost when developing in contexts. The study attempts earnest attempts to extend to the deeper analysis of the implementation of so-called

autonomy-possessed and executed aerial delivery systems as an embodiment of logistics and counter access problems in the distribution systems to critical health.

➤ Significance of the study

The study value lies in the fact that it identifies the role of drone technology and how the latter along with others are bound to transform the current supply chains fully especially in Raviand and Ghana that have their own logistical issues and limitations. Through the discussion of the empirical case studies and operational analysis of Zipline innovations, a practical contribution is expected as to how unmanned aerial systems can decrease the delivery time and the transport cost and also access vital healthcare commodities and products to serve the remote users and geographic locations. The study findings and the results will be useful to the policymakers, the logistics managers, and the developers of technology by providing solutions to the sustainable last mile delivery as the technologies are implemented which are sustainable. In addition, the study contributes supply chain innovation, resiliency, and sustainability research—a quality of scholarship that will be useful at least for additional theory development for foresight-oriented research into challenge areas for applying drones in international logistics networks.

II.LITERATURE REVIEW

Theme 1: Drone Technology in Supply Chain and Logistics Transformation

Drone technology is now a leading facilitator in revolutionizing supply chain management and logistics, proposing alternatives for enhanced speed, cost, and sustainability. Rejeb et al., (2023) reported that drones are being employed to improve humanitarian logistics, shipping times, reduce operation costs, and increase resilience in supply chains. Muricho and Mogaka (2022) reported that the use of drones to facilitate retail logistics is an avenue for economic growth though challenges associated with technical, infrastructural, and ethical issues are slowing the sustained adoption of drones into logistics. As digitalization within logistics or Logistics 4.0 continues to increase, drone technology can be integrated with cyber-physical systems and artificial intelligence to create adaptive and intelligent supply chain (Mihai, 2022). These technologies provide real-time visibility, which improves route planning and also creates

environmentally enticing alternatives from the traditional delivery solution to autonomous aerial logistic networks.

Despite the advantages of utilizing drones in logistics, though the technological performance and viability drone use in the logistics industry has been introduced and the applicable use of drones in logistics are in an experimental stage of the process and necessitates regulations, acceptance, infrastructure shortening the trajectory towards integrating drones into logistics at an operational scale. Di Paolo (2018) indicated while the applications of drones in logistics and especially for last-mile delivery and inventory management and monitoring, are absolutely subject to challenges that could be catastrophic for their operational integration in global logistics systems and their operational and economically viable integration in logistics systems. , Mazur and Borucka (2025) state that there are commercial limits on payload and safety factors with drones limiting drone commercial delivery capacity in logistics systems. Nonetheless, the ongoing data and automation innovations are yielding better performance in drone use reopening their viability as possibilities for urban and rural logistics systems. In summary this theme suggests that not only improving drone performance is positively influential on the supply chain effectiveness but serves as the elements of building sustainable smart logistics systems.

Theme 2: Drones in Healthcare and Humanitarian Logistics

Drones may have a revolutionary role in the delivery of healthcare and humanitarian logistics, especially in parts of the world with little to no infrastructure. Zipline's application of drones in Rwanda and Ghana is a unique change in emergency medical supply chains, creating increased levels of access to healthcare service (Demuyakor, 2020; Gangwal et al., 2019). Both Tetteh et al. (2025) and Bhattacharya et al. (2025) illustrate facts about local groups in remote areas that used drones for vaccine transport, in addition to blood and medical material transport, reducing response times and increasing the efficiency of inventory management. Quazi and Raju (2024) discussed the application of drone analytics on the basis of AI/IoT for optimizing delivery paths, enhancing operational decision-making. Findings in these studies form part of the increasing evidence that the degree to which drones have expanded the accessibility of healthcare

services represents substantive innovation in regard to attaining universal health goals in the spirit of sustainability and equity concerns internationally. Drones have also enhanced disaster relief and emergency logistics in humanitarian situations.

Drones can deliver humanitarian aid and assess damage rapidly according to Alfaris et al. (2024) and Mayor-Vitoria (2025). Oyan (2022) and Al Hmoudi (2020) also indicated drones normally can give warning and rescue in disaster situations but this occurs mainly in developing nations that are exposed to frequent natural hazards. The capability for drones to offer humanitarian and medical logistics means the capability for drones to be used in austere conditions where conventional logistics is not possible. While this does promise some genuine potential, there is still the cost and regulation barrier of the air space, and the training of staff that will prevent execution of these solves on a mass scale. Once more, the humanitarian aspect of drone technology is at another level, with interagency cooperation required in policy and technology integration within digital infrastructure to create long-term effects.

Theme 3: Security, Privacy, and Ethical Challenges in Drone Deployment

As the acceptance of drones increases in the logistics and healthcare areas, the issues of data security, privacy, and operational safety remain barriers to widespread adoption, as discussed by both Altawy and Youssef (2016) and Akram et al. (2017) who point out that, drones based on cyber-physical systems face risks of hacking, data breach, and physical sabotage. The risks that arise from privacy violations amplify when drones are overflowing and travelled as fleets or swarms, whereby unauthorized access could breach mission-critical operations without the authority to do so. Tu and PIRAMUTHU (2024) - for example - considered privacy harms in the context of last-mile delivery drones, where communication signals and global positioning systems (GPS) would allegedly be able to provide access to sensitive information about consumers and logistics operations. Leon et al. (2023) further discussed privacy liabilities harming consumer trust and adoption of drone delivery, which demonstrated public perceptions are largely reliant on how safe their data is and the assurances of legislative protection.

Enayati et al. (2023) imputed the mechanisms of trajectory randomization and differential privacy algorithms to ensure privacy of data loss, which can conclude a trend where cybersecurity frameworks are understood to be embedded into the systems sensibly. Seo et al. (2016) outlined white-box cryptography as a security model, which not only mediates protection for drone operations, but operates against cyberattacks, as a consideration of cybersecurity defense technology - while Das et al. (2020) elaborated on issues around viable IOT-based drone security whilst shopping online contexts. These studies proposed allusion to security, governance, cybersecurity protection, policies and ethical frameworks being more accessible governance for drone operations. Security, cybersecurity, public perception, compliance of data protection and ethical frameworks will constitute an assurance against the governance of drone operations and as further developments of technology for drone operations transpire, the rate of social acceptability or social sustainability will be underpinned by the existence or absence of precautions or privacy protection is a caveat to take account for drone delivery. The future of drone logistics is not simply to measure the levels of technocritical and reliance on compliance to protect privacy, but rather a combination of technological innovation with values if trust, transparency, and compliance with global governance standards.

III. RESEARCH GAP

A noticeable gap in research exists in terms of understanding the broader, long-term economic, social, and operational implications of drone delivery services beyond the value of their immediate healthcare access improvements. While Zipline's infrastructure has demonstrated effectiveness in some limited cases and the delivery of emergency medical supplies in Africa, to date, there are no studies examining the scaling, sustainability, and embodiment of these systems in a variety of different socio-economic and regulatory contexts. The researchers ought to examine the economics and viability of drone delivery systems expansion to cover a broader and more inclusive populace, particularly when they belong to the geographically varied regions with incompletely developed capacity infrastructures. Little empirical research has also been done on how drone service can enhance current supply chains and logistics

operations, without substituting conventional logistics systems. The social implications have also been overlooked, specifically considering the trends in local employment and skill development while measuring consumer acceptance of autonomous delivery services outside of healthcare services. Lastly, there are technological gaps around payload weight, operational range, and adaptive to environmental frameworks that require further advancement before reliability and inclusivity can be expected in future drone delivery logistics models.

IV. STATEMENT OF THE PROBLEM

While the Zipline delivery model has shown promising performance trends to expand healthcare access the overall scope of economic, social and logistical conditions of drone deliveries are still little understood, such as performance measures across regulatory and infrastructure conditions. There is little research regarding the long-term scale and sustainability of drone technology to integrate into existing supply chains suggesting caution and uncertainty of being a legitimate logistics solution. Additionally, there is little research around its economic cost-effectiveness, impacts on the workforce, or whether it may have general implications for consumer acceptance beyond medical emergency relief. Technological limitations (e.g., limited payload weights, limited coverage, and extreme weather conditions) also hinder optimal, widespread adoption. Therefore, the lack of comprehensive research that integrates the technological, economic, and social aspects of drone-enabled delivery systems and services may negatively affect the development of evidence-based policies, networks, and scalable models that are intended to promote long-term benefits and value across multiple regions.

V. RESEARCH METHODOLOGY

The study adopts a mixed methodology that focuses on qualitative and quantitative data to bring light on how the Zipline technology and drone-based logistics can improve supply chain operations to increase the efficiency of Rwanda and Ghana. An interview questionnaires guide was designed to collect data on 200 stakeholders of Zipline operations, and statistical data were handled with the help of MS Excel and SPSS 27.

➤ Research Design

The research design used in the study was descriptive and exploratory that determined the current practice and analyzed the innovations of drone-based logistics within the supply chain of Zipline. This study design has enabled the researcher to study the interplay between the adoption of technology and the performance of the operation.

➤ Sampling and Data Collection

The study collected data of various stakeholders associated with Zipline dispersed in Rwanda and Ghana, which requires the application of stratified random sampling design to extract data. The data was collected with the help of both primary (structured questionnaires) and secondary source of information (reports, publications) and analyzed in the context of mean, standard deviation, and regression.

VI.CONCEPTUAL FRAMEWORK

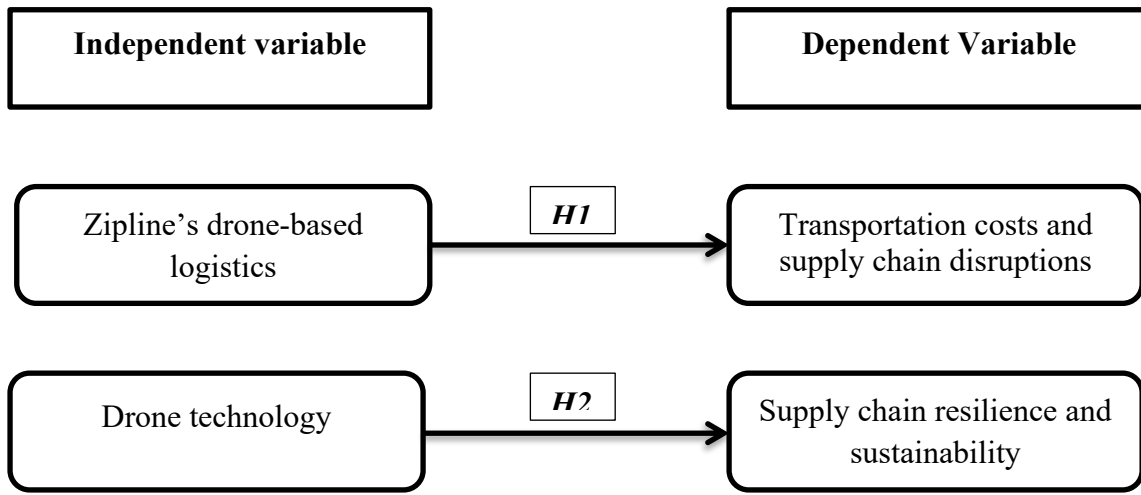


Figure 1: Conceptual Model

VII.Result and Discussion

Table 1: Demographic Characteristics

S.NO.	Demographic Characteristics	N	%
1	Gender	Male	47.50%
		Female	52.50%
2	Age	18–25 years	14%
		26–35 years	26.50%
		36–45 years	20%
		46–55 years	18.50%
		Above 55 years	21%
3	Educational Qualification	Bachelor's Degree	21%
		Master's Degree	20%
		Diploma	17%
		Doctorate	18.50%
		Professionals	23.50%
4	Role in Supply Chain	Government Official	18.50%
		Zipline Operator	22.50%
		Healthcare Professional	24.50%
		Logistics Manager	16.55%
		Supply Chain Expert	18%

5	Years of Experience in the Sector	Less than 1 year	39	19.50%
		1–3 years	43	21.50%
		4–6 years	37	18.50%
		7–10 years	42	21%
		Above 10 years	39	19.50%

The respondent demographics proved to be gender even at 47.5% males and 52.5% females even though they were regarded as representative. The highest age percentage of respondents (26.5) of 2635 years with a relatively younger active workforce at a stable supply chain industry with the respondents of the younger ages falling equally in the age bands, albeit with less proportion of the younger ages above cohort analysis cutoff with a heterogeneous experience profile. The education status of the respondents also exhibited they are a fairly qualified labor force, with a significant number having professional degrees (23.5%) and bachelor's or master's degrees (41%). The work in the supply chain industry varies with healthcare providers (24.5%) along with Zipline operators (22.5%) as the most predominant area of work being reported which suggest Zipline's operational and

health convergence. Respondent experience is well-adjusted and equally balanced, most reporting 1-3 years (21.5%) or 7-10 years (21%) of experience, suggesting that a range of both new and experienced professionals participated in this study. Overall, the demographic information shows diversity and participant representation in experience and knowledge applicable to Zipline's drone logistics.

Hypothesis Testing

Objective 1: To evaluate the impact of Zipline's drone-based logistics on transportation costs and supply chain disruptions.

H1: There is a significant impact of Zipline's drone-based logistics on reducing transportation costs and minimizing supply chain disruptions.

Table 2: Model Summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.284 ^a	.081	.076	2.70052
a. Predictors: (Constant), Zipline's drone-based logistics				

The information provided in Table 2 about the model summary shows that there is a low to moderate correlation coefficient (R = 0.284) for the positive association between Zipline's drone-based logistics and the dependent variable (e.g., transportation cost, supply-chain disruptions), and the R Square value is equal to 0.081. This means that 8.1% of the variation in the dependent variable can be explained by Zipline's drone-based logistics. The Adjusted R Square value of 0.076 means that when sample size and the number of predictors is adjusted

, the model will still have a moderate ability to explain variation in the dependent variable. The standard error of the estimate, which is equal to 2.70052, means that the average difference between the estimated values and the actual values is minimal, but nonetheless, there is variability in the predictions. The ANOVA in Table 3 shows the model which uses Zipline's drone-based logistics to predict transport expenses and supply chain disruptions is statistically significant

Table 3: ANOVA^a

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	126.821	1	126.821	17.390	.000 ^b
	Residual	1443.974	198	7.293		
	Total	1570.795	199			

a. Dependent Variable: Transportation costs and supply chain disruptions
b. Predictors: (Constant), Zipline’s drone-based logistics

The regression sum of squares (126.821) reflects the variance that is explained while the residual sum of squares (1443.974) reflects the variance that is unexplained, which is suggested because even though the model is statistically significant, there is still a considerable amount of variance that is being influenced by factors that are not considered in the model. As noted, there are 198 degrees of freedom in the residuals and 1 degree of freedom in regression, which confirms that Zipline's drone-

based logistics is statistically significant for lowering transportation costs and for reducing disruptions in the supply chain. This finding substantiates the first hypothesis (H1) that drone-based logistics will lead to significant improvements in efficiency within any supply chain context. In addition, the coefficients table (Table 4) provides further insight into the extent to which Zipline's drone-based logistics reduce transport costs and transportation disruptions within the supply chain.

Table 4: Coefficients^a

Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7.042	.710		9.913	.000
	Zipline’s drone-based logistics	.279	.067	.284	4.170	.000

a. Dependent Variable: Transportation costs and supply chain disruptions

The unstandardized coefficient (B = 0.279) indicates that there is a 0.279-unit increase (decrease in disruptions or costs) of the dependent variable for every one unit increase in the efficiency of Zipline's drone-based logistics, holding all other variables constant. Furthermore, the standard coefficient (Beta = 0.284) indicates that the effect size is moderately positive and is consistent with the previous model summary (R = 0.284). With a t-value of 4.170 with a level of significance (p = .000), the relation is demonstrated statistically significant at the .05 which reiterates the significant and consistent association of the predictor variable with the outcome. The constant (7.042) illustrates the average level of transportation expenses and

disruptions to the supply chain at the zero level or without Zipline's drone-based logistics model. The Model Summary in Table 5 presents the correlation between drone technology and the dependent variable, supply chain sustainability and resilience. The correlation coefficient (R = 0.190) reflects a weak but positive relationship between the two variables.

Objective 2: To examine the role of drone technology in enhancing supply chain resilience and sustainability.

H2: Drone technology significantly enhances supply chain resilience and contributes to the sustainability of logistics operations.

Table 5: Model Summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.190 ^a	.036	.031	2.67197

a. Predictors: (Constant), Drone technology

The value of R Square is .036 which suggests 3.6% of the variation of the supply chain sustainability and resilience is explained by the variable of drone technology. The value of Adjusted R Square is .031 (close enough on specification), which indicates the model has little explanatory power in adjusting the

sample size and predictor variable of drone technology. The measure of the standard error of estimate (2.67197) reveals a moderate level of deviation between the observed and predicted values. While the predictive power of the model remains relatively low, the positive correlation

indicated that innovation in drone technology does promote some reality of enhanced supply chain resilience and sustainability, but little reality. The output of ANOVA presented in Table 6 suggests statistical significance in the regression model fit of drone technology on supply chain resilience and

sustainability. The F-value of 7.451 and significance (Sig. = .007), is significant in that it is below the cutoff of .05 indicating that the regress model is a good fit for the sample and that the predictor variable (drone technology) significantly accounts for the variance in the dependent variable.

Table 6: ANOVA^a

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	53.193	1	53.193	7.451	.007 ^b
	Residual	1413.602	198	7.139		
	Total	1466.795	199			
a. Dependent Variable: Supply chain resilience and sustainability						
b. Predictors: (Constant), Drone technology						

In addition, the R Square value is .036 showing that 3.6% of the variation in supply chain sustainability and resilience explained by drone technology. Furthermore, after adjusting sample size and number of predictors the Adjusted R Square is .031, which is in close proximity indicating there is very little explanatory power for the model. Standard Error of Estimate is (2.67197) is indicative of a moderate variate between the actual observed and predicted values. Needed to be noted that while the predictive power remains fairly low, there is a small positive correlation suggesting that some form of innovation

in drone technology will contribute to supply chain sustainability and resilience albeit little. As repeated as it was above, the output of ANOVA present in Table 6 suggests statistical significance for the regression model fit of drone technology on supply chain resilience and sustainability. The F-value of 7.451 with a significance level indicator (Sig. = .007) which is lower than .05. This indicates this model is a good fit and the predictor (drone technology) significantly explained variability in the outcome variable.

Table 7: Coefficients^a

Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7.877	.838		9.404	.000
	Drone technology	.207	.076	.190	2.730	.007
a. Dependent Variable: Supply chain resilience and sustainability						

The t-value of 2.730 with its associated significance (p = .007) confirms it is statistically significant at the .05 level. This means that drone technology provides a measurable effect on the resilience and sustainability in logistics operating methods. The constant (7.877) represents the base supply chain resilience and sustainability for the example for a case where drone technology is not utilized. The wide-scale diffusion of the Zipline drone delivery model is greatly moderated by regulatory issues, infrastructure barriers, and policy constraints that affect its overall adoption into global and national supply chains (D³ Harvard 2022). Regulatory issues are still strong tasks as drone delivery models like

Zipline are subject to varying aviation regimes by jurisdiction, with the United States Federal Aviation Administration (FAA) being strict on aviation practices and procedures with arduous certification and Beyond Visual Line of Site barriers to scale. The European regulatory landscape is no less strict and sometimes unclear on the permission required by the commercial drone flights, particularly when there is thin distribution of the likely people (McKinsey & Company 2023).

Objective 3: To identify challenges and policy barriers associated with large-scale adoption of Zipline’s drone delivery model and propose

strategies for its integration into global and national supply chain networks.

H3: The large-scale adoption of Zipline's drone delivery model is influenced by regulatory challenges, infrastructural constraints, and policy barriers affecting its effective integration into global and national supply chain systems.

The widespread implementation of the Zipline drone delivery scheme is subject to policy considerations, regulation, and infrastructure, which affects the general implementation of the drone delivery scheme in supply chains across the world and the broader national level (D3 Harvard 2022). The regulatory overload remains a challenge in and of itself, especially when it comes to the drone delivery networks such as Zipline; the networks are subject to complex aviation regulations that are highly dissimilar across locations; the U.S. Federal Aviation Administration (FAA), in particular has strict certification protocols in addition to a ban on Beyond Visual Line of Sight (BVLOS) operations, which creates drag in terms of implementation and scale. The findings also align with the available literature that Demuyakor (2020) and Tetteh et al. (2025) cited relating to the use of drone technology created by Zipline that has improved healthcare delivery in rural Africa, in terms of delays and product loss.

Europe is noteworthy to cite here as well, since such contractors also have similarly stringent, and sometimes complex rules with different linear authorizations for commercial drone use, particularly in metropolitan areas (McKinsey & Company 2023). To illustrate, one among many policy barriers, has created situations in which large major drone companies are beginning to develop in less populated countries with a more tolerant approach (an example would be countries like Rwanda and Ghana), where their success can be attributed to varying government cooperation and more specific aviation support in countries such as those (Orion Journals 2024). In addition to the environmental issues with regulation, Zipline is also dealing with locations with infrastructure and other social issues, which affect the ability to employ successfully and effectively (UPDWG 2024).

Limitations regarding battery life, weight, and flight issues in urban spaces (air space deconfliction) related to flying commercially with large payloads are headline challenges for widespread drone

delivery. Infrastructure needs—dedicated distribution sites, charging stations, and air traffic control—require collaborative investment and planning (Reach Alliance 2021). Public acceptance, privacy, and noise issues are significant factors in public and local authority resistance to drone delivery and associated policy and market development (ScienceDirect 2023). Zipline, and others, will require to promote collaborative commercial structures for legislation, embrace innovative solutions, create a trusted public-private partnership, and optimize drones into existing infrastructures—sharing capacities on the basis of supply chain data, IT interfaces, and defined operational routines centrally positioned in the thinking behind their enterprise strategic plan (Statzon 2025).

➤ Discussion

The study shows that the Zipline drone logistics model makes transport cost savings and supply chain disruptions statistically significant ($F = 17.390$, $p < .001$) and exhibits unmanned aerial delivery efficiency and responsiveness (D³ Harvard, 2022). This is as per existing research (Rejeb et al., 2023; Muricho & Mogaka, 2022), which established that increased deployment of drones enabled more nimble, economical, and robust logistics networks. In accordance with the second hypothesis, drone technology has a high impact on supply chain sustainability and resilience ($F = 7.451$, $p = .007$), in accordance with Mihai (2022) that digital logistics via automation and AI may help improve supply chain responsiveness. However, the low R^2 (0.081 and 0.036) values meant that although the drones play an important role, there are other operational, regulatory and infrastructure factors that influence the performance of supply chains. Generally, the study validates the revolution of drone logistics in putting in place a sustainable, fair, and resilient supply chain system, policy supports requirements and technological adaptability. By way of conclusion, the study demonstrates that drone technology chemicals transport disruption delays diversification in a way that improves the sustainability and resilience of the supply chains.

VIII.CONCLUSION

The study concludes that how technological innovation addresses certain of the logistics challenges of traditional channels for essential goods, and is delivering service in more off-grid and

underserved locations. Moreover, the integration of drone systems will provide a more agile, information-driven, and user-friendly-to-sustainability-and-accessibility platform in the supply chain ecosystem. To sum up, the study results in the conclusion that the implementation of drone logistics can transform the old system of distribution into an efficient, fair, and innovative system according to the new world. In the process of reporting the results of the study, it was observed that the drone-based logistics of Zipline is an essential change in healthcare and supply chain management in developing countries. The integration of drone technologies creates a more informed data, agile, and responsive supply chain that is in harmony with the principles of the present-day relating to access and sustainability.

➤ Limitation

The study identifies the potential of drone logistics to transform traditional distribution systems into new, effective, and fair delivery systems to provide services to a rapidly developing world. To make conclusions about the study, the controversy proved that Zipline drones' logistics served as the center of interest in the supply chain management and revolutionization of health care in the developing regions. The authors conclude that the chemicalization of transport delays and disruptions with the help of the drone's technology enhances the resilience and sustainability of the supply chains. A comparative analysis of both the developed and developing world would offer more sophisticated understanding of flexibility of the regulations, the readiness of the infrastructure and cost-effectiveness.

➤ Future Research Directions

The academic literature will also have the task of discovering the viability and readiness of the above study topic to integrate with future technologies or equipment like artificial intelligence, blockchain, and the Internet of Things to amplify any real-time surveillance, data security, and forecasting analytics capability of the SNES supply chain. Social and environmental consequences of introducing drone to the society such as displacement by the workforce, acceptable use of the drones in society and reduction of carbon emission can also be investigated in the future research to inform the policies used in the development of inclusive and sustainable outcomes. The study is limited in the consideration of discrete

geographic sections (Rwanda and Ghana) that limits the generalization to various regulation, infrastructures and socio-economic environments.

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