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ARTICLE

From Land to Sky: Understanding the Challenges and Opportunities of Drone-Driven Food Delivery in Malaysia

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ABSTRACT

With the ongoing industrial revolution, the innovative approaches to marketing strategies are being introduced, including the drones' usage of online food delivery services. However, drone adoption involve into the food delivery sector remains limited and has yet to take hold in Malaysia. While drones are already utilized in various Malaysian industries—such as border security surveillance, aerial photography, and disaster relief operations, including the delivery of critical supplies during floods—the food delivery industry has not yet embraced this technology. This study seeks to prolong Technology Readiness and Acceptance Model (TRAM) by integrating delivery risk as main independent variable to better understand individual behavior toward adopting emerging technologies. Gaining deeper insights into these human factors can assist decision-makers and marketers in crafting strategies that better align with customer expectations. Specifically, two new constructs—delivery risk and generation gap—were incorporated into the model. The extended framework was empirically tested using a quantitative approach within the Malaysian context. Out of 400 questionnaires distributed, 384 valid responses were obtained. The results indicated that respondents' views did not fully align with the hypothesized relationships concerning the two additional constructs and their influence on adoption intention, particularly regarding drone use in food delivery services.

Keywords: Adoption Intention; Food Delivery Services; Drone Technology; Drone Application; Drone Usage

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1. Introduction

Drones delivering food represent an emerging technology that combines convenience, speed, and innovation. By utilizing autonomous or remotely controlled drones, food deliveries can reach consumers more quickly and efficiently, particularly in areas with high traffic congestion or challenging terrain. Companies such as Uber Eats and Domino's have already initiated trials of drone delivery systems, providing a glimpse into the future of food logistics.

The logistics industry faces both new challenges and opportunities, driven by digitalization and the rapid growth of e-commerce. The integration of artificial intelligence (AI) and autonomous flight technology marks a significant advancement in drone capabilities. Looking ahead, drones are expected to introduce greater creativity and efficiency across various industries [1]. Furthermore, these systems are projected to streamline the transportation of a substantial portion of consumer goods ordered on demand [2]. Despite this potential, the widespread use of drone delivery remains relatively limited due to factors such as public perception, regulatory restrictions, and technological challenges [3]. However, several major U.S. companies have launched initiatives to expand drone deployment for delivery, approved by the Federal Aviation Administration (FAA). These companies have also formed strategic partnerships with prominent retailers to extend their coverage to larger geographical areas within the U.S. Additionally, plans are underway to expand drone delivery operations into six new European markets by 2023 [4].

Several factors have driven the rising demand for drones, including advancements in technology, shifting consumer preferences, and an increasing need for faster and more efficient delivery solutions. In particular, the Covid-19 pandemic spotlighted the potential of drones' usage in food delivery services. Drone-based package delivery systems are projected to grow substantially in the global market from 2018 to 2030, reaching an estimated value of USD 3.4 billion by 2030 [5]. Utilizing drones reduces dependence on human drivers, offering advantages such as quicker delivery times and better preservation of food during transit. Especially in suburban areas, drone-based delivery is expected to outperform traditional methods in terms of efficiency [6].

Moreover, the pandemic has accelerated demand for delivery services as mobile robotic systems help minimize direct human contact during parcel delivery. Consequently, delivery drones have emerged as one of the most innovative alternatives, capable of transporting parcels via air [7]. The food service industry has witnessed significant investment aimed at developing drone delivery capabilities that not only promise rapid delivery but also the ability to overcome traffic congestion and geographic barriers.

The impact of COVID-19 has notably fueled growth within the drone delivery sector, opening up substantial opportunities in the logistics and delivery industries. Data from Statista's Global Consumer Survey [8] reveals varying levels of readiness for drone delivery technology across countries. For example, an October 2021 survey found that 26% of respondents in China expressed a preference for drone deliveries, whereas only 14% of German respondents showed a similar willingness.

The emergence of drone delivery services in the Malaysian food industry is a new phenomenon. Drone delivery is a relatively new concept in Malaysia's market. The use of drones as a last-mile courier service is a potentially attractive method, but its uptake in the Malaysian food-delivery sector is not encouraging yet. One of the explanatory factors lies in the dearth of empirical studies that critically challenge how consumers react to such devices. In comparison with the active scholarship carried out in the United States [9] and South Korea [10,11], research in Malaysia is humble in scale and depth. Therefore, the participants of the nascent Malaysian market have to deal with propositional uncertainty and reluctance towards the implementation of drone-based platforms.

The use of drones in food delivery in Malaysia is clearly in its infancy. The development of such a sector is accompanied by a range of obstacles, but one of the most significant is the fact that empirical studies of customer behavior in three-party logistics (3PL) environments involving drones in the Malaysian marketplace are barely existent. Compared with other studies regarding similar food-delivery implementations in the United States and

South Korea [10,11], the current Malaysian state is lacking in similar depth and scale. This lack of indigenous information may refresh doubt and reluctance among the stakeholders deliberating the integration of drone technology within the Malaysian food-delivery system.

Drones have attempted to utilize marketing tactics that are well studied in other fields, a need for more empirical studies that utilize well-known and tested theoretical models to overcome knowledge gaps and better present the factors behind drone delivery acceptance. Proven theoretical frameworks and lenses for evaluating social dynamics serve as the basis for quality research in qualitative interpretive studies. However, drone' research has yet to meet these marketing knowledge bases due to many models being developed for traditional marketing environments. Given the current knowledge gaps, there is an urgent need to conduct more empirical studies that utilize proven theoretical models to address these knowledge gaps and better understand the ways in which people accept drone delivery services.

The industrial revolution is pushing the search for novel marketing methods all over the world, including drone delivery of food. Drone adoption in Malaysia's food delivery market is low despite the high global acceptance of drones. Drones have been used for a variety of industries in Malaysia, from border security surveillance to aerial shots, food delivery, agriculture, topographic mapping [12,13], and an array of disaster relief activities, including delivering flood aid packs [14]. However, Malaysia has not embraced drone technology for food delivery yet. In contrast, several other countries have successfully embraced drone technology for food delivery, setting a precedent for potential adoption in Malaysia.

The reliance on human riders in current food delivery services presents numerous challenges, particularly concerning safety and ethical conduct. Statistics reveal a troubling trend: in 2020, approximately 1600 fatalities were reported among riders engaged in p-hailing services for food and parcel delivery, highlighting the risks associated with navigating congested traffic [15]. Contributing to this issue is the pressure on riders to maximize their income, often resulting in reckless behavior on the road. Research indicates that two-thirds of delivery riders disregard traffic regulations in their pursuit of higher earnings, and one-third engage in serious safety violations such as using mobile phones while riding, ignoring traffic signals, making illegal turns, and riding against the flow of traffic [16].

The surge in demand for contactless services, such as food delivery, creates an opportunity for the adoption of drones in this sector. This shift also aligns Malaysia with the Fourth Industrial Revolution (IR 4.0) by allowing the accumulation of large amounts of raw data, integrating software, leveraging AI, supporting autonomous flight, facilitating machine learning, and connecting to Internet of Things (IoT). These technologies make drones integral components of this technological transformation. These technological developments are encouraging Malaysian society to reassess its stance toward drone innovation. The incorporation of drone technology into Malaysia's innovation ecosystem aligns with the revolutionary potential of Industry 4.0. This technology has the potential to create a flexible, technologically literate populace capable of adapting to changing consumer needs, rather than just facilitating automation.

However, this excitement is tempered. Policymakers face difficulties in assessing the technology's practicality and repercussions due to a lack of empirical and theoretical bases. Existing work, such as Chamata [17] and Nier et al. [18], focuses mostly on drone use in logistics—specifically, warehouse surveillance and package delivery—while the link between drone-assisted food delivery and customer behaviour is relatively unknown. As important issues remain, this study aims to provide the required, rigorous knowledge that the domain has lacked.

Researchers have suggested several ways to understand why people start using new technologies. Some of the most well-known theories include the Theory of Reasoned Action (TRA), the Theory of Planned Behaviour (TPB), the Technology Acceptance Model (TAM), and the Unified Theory of Acceptance and Use of Technology (UTAUT). Each of these offers a different angle, blending both social and technical perspectives to explain what makes people comfortable with technology—such as how much control they feel, what others think, how easy they find it to use, and whether they think it's genuinely useful [19].

Among these approaches, the Technology Readiness and Acceptance Model (TRAM) has proven especially useful for looking at how people might feel about using drones in food delivery services. What makes TRAM stand out is that it pulls together two key theories: TAM, which looks closely at users' opinions about specific technologies, and Technology Readiness (TR), which focuses more broadly on how open someone is to technology in general [20]. The Technology Readiness Index (TRI).

Compared to other models of technology acceptance, TRAM does a stronger job of predicting what people will actually do. This edge comes from the way it combines TAM's focus on technology with TR's broader look at attitude; together, they build a fuller picture [21]. Because TRAM brings these ideas together, it's especially good at forecasting and exploring whether people are likely to accept and use drones for delivering food—making it suitable for many types of research. For these reasons, TRAM underpins this study due to its adaptability and solid track record in predicting outcomes.

Beyond that, this research goes a step further by adding new pieces to the TRAM framework to better explain how people behave. Specifically, it factors in delivery risk, which is expected to impact perceived usefulness, ease of use, and whether someone intends to use drone delivery. It also considers generational differences, treating age as a variable that may change how the rest of the model's factors interact.

This report provided readers an overview of the drone usage in Malaysia's food delivery sectors. Following this introduction, the study continue with reviewing current literature on drone technology acceptability before developing our theoretical framework and research proposals. We then discuss our methodological approach and data gathering processes. Our empirical findings and interpretation are presented in the next part, and the study concludes with a discussion of limits, practical consequences, and prospects for further research.

2. Literature Review

2.1. Technology Readiness and Acceptance Model (TRAM)

When considering the framework (theoretical architecture) that underpins scholarly research on the topic of technology adoption, the Technology Readiness and Acceptance Model (TRAM), as shown in **Figure 1**, is at the center stage. Integrating the Technology Readiness Index (TRI) and the Technology Acceptance Model (TAM) models, TRAM provides a multidimensional framework through which future behaviour relative to the adoption of new technologies can be examined. The model assumes the primary importance of lifelong inclinations of personality on the interaction of an individual with the development of new systems, as well as their acceptance of them. In particular, it couples the dispositional variables of TRI and the context-specific-related perceptions of TAM, providing a predictive mechanism better than analytical methods that only exploit one of the two associated fields [20,22]. In practical terms, both the human predispositions and situational perceptions form the basis of integrating requisite practical strategies of initiating new technologies in application.

In TRAM (Technology Readiness Acquisition Model) construct, the critical postulation is that the level to which an individual is ready technologically has a decisive impact on two traditional constructs of the TAM model, namely perceived usefulness and perceived ease of use. This pressure is realised through four main facets.

The Technology Readiness Index (TRI) has the dimensions that are used in the Technology Readiness Assessment Model (TRAM) to assess to readiness of an individual in adopting emerging technologies. Scholars observe that these dimensions are antecedents of both perceived usefulness — the amount to which adopters feel that the system will positively influence performance at work, and perceived ease of use — the lower amount to which the system is believed to demand little effort to use [24].

Fellow researcher, empirical usefulness and anticipatory validity of the Technology Readiness Assessment Model (TRAM) have been continuously established in a multiplicity of research settings. As a case in point, one can mention its use to predict the attitude toward health and fitness apps and its deployment in predicting the adoption of data standards in smart cities [23] and to study the mobile banking adoption in developed and developing countries [25].

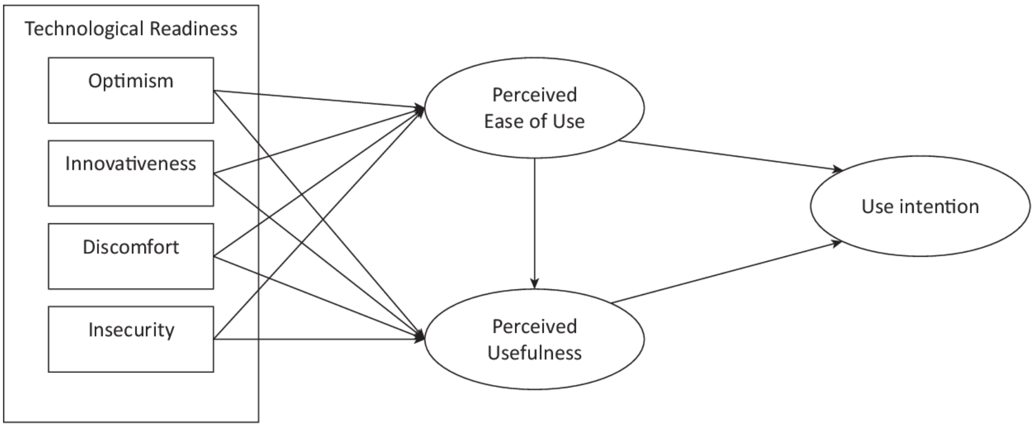

Figure 1. Technology Readiness and Acceptance Model (TRAM).

Source: Buyle et al. [23].

One of the most outstanding findings of this literature that is quite consistent is that the chances of technology adoption are greatly enhanced in a scenario where usefulness and perceptions of ease of use are positive. This has had the strength to make TRAM a good building block in studying drone technology in food delivery as applied in Malaysia, as in the current investigation.

At the outset, we should locate where this scholarly endeavor finds theoretical origins within the four dimensions of TRAM, that is, optimism, innovativeness, discomfort, and insecurity and which is the scaffold of our taxonomy. However, as the field of drone delivery is quite a different topic, unlike many technology adoption studies, there was a need to add extra constructs to the TRAM outline to add to the predictive power of the model.

Most importantly, is inclusion of the concept of attitude toward adoption is crucial to most theories of behaviour [26]. In a literal sense, attitude refers to the global evaluation of a person towards the act of using and relying on drone delivery services, and it serves to act as a central and primary antecedent to behavioral intention. The model also pays tribute to the timeless pillars of TAM: perceived usefulness and ease of use, whose effect on adoption intention has been stringently confirmed in the previous technology adoption literature [17,24].

To explain the specifics of unmanned delivery systems, the current discussion proffers a new concept of delivery risk. The existing literature lists the extent of risks involved in drone activities, the most evident of which are security risks, including hacking, hijacking [27] and physical risks regarding mid-air disasters [28]. It puts forward a hypothesis that perceptions of these risks will have an inverse effect on adoption intentions.

The cornerstone of the analysis is that an understandable gap in research is perceived: the generation gap is suggested as a relevant moderating variable. Even though the empirical research into the generational attitudes to drone technology is at an early stage, current evidence suggests clearly that these patterns of adoption and individual perceptions of drone technology is much varied across age groups [29]. The exploration of this aspect will be crucial in determining how drone technology will likely be adopted on a large scale in the delivery of food.

2.2. Adoption Intention

In their seminal work, Venkatesh et al. [30] observe that adoption intention constitutes the most direct and immediate predictor of actual technology use, effectively functioning as a critical mediator that links user perceptions with subsequent behaviour. Empirical findings consistently reveal that users' intentions to adopt innovations, such as Internet banking, directly correlate with increased transaction volume and improved profitability for banks [31].

The given theoretical framework is especially enlightening when it comes to the emergent practice of food delivery through drones. In order to take full advantage of the potential of this technology, it is necessary to develop strong adoption intentions both on the side of the customers and the service providers. The evidence indicates that users' intentions to adopt are positively shaped by their perceptions of novelty and practical benefits [32]. In the specific case of drones, perceptions of cost savings, delivery speed, and environmental friendliness operate as salient motivating factors, resonating well with contemporary consumers' preferences for convenience and rapid service [9].

When evaluating the determinants of adoption intention in digital services, we should note that functional advantages do not reflect the entire range of motivations. Empirical work on online food delivery systems underscores the significance of psychological constructs such as attitudes, perceptions, and convenience-related motives in fostering engagement with such platforms [33]. Likewise, social influence has been shown to exert a decisive influence on technology uptake more broadly [34]. Within the drone-delivery domain, evidence indicates that marketing initiatives, individual technological readiness, and personal innovativeness collectively shape adoption intentions [35].

However, even though these are positive signs, the potential acceptance of drone delivery is tempered by the perceived risks. Yoo et al. [9] establish privacy, delivery reliability, systems performance, and operational complexity as salient barriers. Consistent with this finding, Knobloch and Schaarschmidt [36] identify physical hazards, financial losses, and data-security threats as significant areas of concern, thereby underscoring the imperative for service providers to implement rigorous risk-management strategies. Therefore, although the initial response to drone-based food delivery is positive, the overall adoption is only possible with the active elimination of the risks described above. Through the implementation of strong privacy, security, and reliability protection measures, the stakeholders will be able to build consumer confidence and increase the likelihood of a wider market success.

2.3. Predictors of Adoption Intention in Using Drone Technologies

A wide range of factors impact people's intentions to embrace new technology, including personal traits like education, experience, and demography, as well as cognitive judgements of the technology itself. Given its diverse character, a solid theoretical framework is required to carefully investigate the major factors of adoption.

The Technology Acceptance Model (TAM) is one of the most commonly recognised theories in this subject, with several empirical investigations demonstrating its strong predictive potential. TAM claims that an individual's desire to use technology is mostly determined by two key perceptions: perceived usefulness and perceived ease of use [24]. According to this concept, adoption is most likely when consumers feel the technology would improve their performance with low effort. This framework serves as a basis for examining adoption intentions related to drone technology.

2.4. Antecedents of Perceived Ease of Use

Perceived Ease of Use (PEU) refers to the degree to which a user believes that operating a technology will be free of effort or difficulty [24]. It reflects subjective evaluations of a system's simplicity and user-friendliness. PEU has been consistently shown to influence technology acceptance and user behavior strongly [37].

The precise characteristics of PEU vary depending on the scenario. In digital services, this comprises intuitive interfaces, clear communication, simplicity of navigation, and quick access to information [38]. For example, Ozturk et al. [39] identify PEU as a significant contributor to loyalty intenttions in mobile hotel booking, with its impact magnified when services are closely aligned with user demands.

Beyond the user interface, PEU refers to operational ease throughout technology integration. Wang and Ha-Brookshire [40] discovered that Chinese textile manufacturers preferred technologies that were easy to integrate into their operations and complemented employees' existing expertise.

Introducing drones into the food delivery scenario creates new operational needs for both suppliers and customers, necessitating fresh skills and relationships that differ from traditional logistics. To maintain safety and efficiency, the human-machine interaction must be intuitive throughout the flight control and package gathering processes.

Thus, knowing consumers' expectations for the usefulness of drone delivery systems is crucial. The perceived ease of use impacts consumers' confidence and competence; hence, PEU is an important factor in determining the usefulness of this technology in food delivery.

2.5. Antecedents of Perceived Usefulness

Within contemporary technological scholarship, Perceived Usefulness (PU) is frequently defined as an individual's judgment that the employment of a specific technological artifact will improve task performance or overall effectiveness [24]. Such judgment is grounded in the assumption that the technology facilitates the completion of tasks in a manner that is either easier or more efficient [41]. When users discern these advantages, their attitudes toward adoption turn out to be appreciably more favorable [42].

The salience of PU has been successfully proved in many areas. Tahar et al. [43] demonstrate, for instance, that PU substantially influences user adoption of e-filing systems by streamlining tax-related activities. In a parallel fashion, Singh and Sinha [44] show that perceived advantages in security and convenience exert a strong influence on retailers' use of mobile wallets. Following up on these results, we expect that PU will also have an equally positive effect on the intentions to use drone delivery, as consumers have a strong tendency to use technology that provides faster and more convenient food delivery.

2.6. Delivery Risk

Delivery risk refers to the potential loss associated with the delivery process, encompassing issues such as goods being lost, damaged, or delivered to the wrong location after a transaction is made [45]. It also includes the risk of experiencing delays or not receiving the product at all. Consumers are often concerned about delivery risks for several reasons. Firstly, they worry that the firm may deliver the product late or not within the promised time frame, which could be due to various circumstances [46]. Secondly, consumers fear that goods may be damaged during transportation due to inadequate packaging. As an online retailer, it is crucial to ensure that products remain undamaged and unexpired during delivery and to provide efficient and accurate delivery services. When merchants can offer accurate delivery services to customers, it increases confidence in placing orders and reduces perceived delivery risks [47].

Uncertainty about regulations is a fundamental issue. Ngui [48] emphasised that drone delivery operates in an uncontrolled and potentially unsafe environment. The lack of a clear and rigorous legal framework might lead to misunderstanding and increased concern among potential adopters, deterring food service businesses from investing in and incorporating drone technology into their operations [11].

Essentially, delivery risk highlights the possibility that service providers may fail to fulfill their commitments to customers—an issue that becomes particularly pronounced when using drone or UAV technologies for food delivery.

Drone systems have substantial technological and operational weaknesses in addition to legislative constraints. Research has found multiple possible failure sites, including hardware malfunctions such as sensor, motor, or gearbox failures, software and logic system problems, battery depletion, and fire threats [49,50]. External dangers to drones include accidents with obstructions and hostile attacks such as hacking or physical sabotage [49]. These inherent technical risks necessitate the implementation of comprehensive contingency plans and precautionary measures to ensure service reliability.

These dangers have a direct influence on user trust and desire to adopt. Hwang and Choe [12] discovered that time-related, performance, and psychological risks reduce perceived dependability of drone services, lowering adoption intentions across both consumers and providers. This is supported by Khan et al. [51], who discovered in Pakistan that a high level of perceived delivery risk was a major obstacle to shops shifting to drone-based systems. Physical danger, financial loss, data privacy breaches, noise pollution, and surveillance concerns are among the many perceived hazards that service providers must handle proactively [36].

To summarise, the research clearly indicates that delivery risk is a significant and complicated obstacle to the general deployment of drone technology in the food delivery business. While technology innovation is critical to reducing technical failures [52], a comprehensive risk mitigation plan is required. To prevent service failures, service providers must undertake comprehensive risk assessments and adopt strategic strategies. Understanding how potential users perceive these complex hazards is thus vital for forecasting adoption intentions and nurturing the consumer trust necessary for market acceptability.

2.7. Generation Gap

The concept of a generation gap refers to the differences in values, beliefs, and behaviors that often separate one generation from another, potentially causing misunderstandings and tension, especially within families [53,54]. This gap has always existed, however, it has increased significantly over the last few years as a result of how fast the technological world is changing. How different age groups accept and adjust to new technologies has added layers of communication challenges, making the generation gap a crucial factor in studies about technology acceptance [55].

This is a gap that is evidently manifested in various disciplines. In digital health, for example, older generations tend to be more cautious about online health services compared to younger, tech-savvy groups, which results in lower usage of e-Health platforms by the elderly [56]. Likewise, in the context of education technology, Generation Z instructors who have spent their childhood in a digital age tend to be more motivated and comfortable with such tools as generative AI. On the other hand, Generation X educators, who encountered such technologies later in life, approach them with more skepticism due to their more limited early exposure [57].

Studies conducted recently refute the idea that the younger generations naturally adapt to technology than older populations. Instead, adaptability is revealed as the important variable impacting the use of technology in all generations. It has been demonstrated that the open and flexible individuals are more likely to adopt technological changes irrespective of their age group. This observation implies that the generational digital divide can be overcome through training and positive workplace cultures that would allow older adults to use new technology as well as young people. These subtle differences in generations and the element of adaptability a crucial things to consider when analysing the adoption of technology. Being conscious of the fact that every generation possesses its own relationship with technology can assist in planning even more comprehensive approaches that will be more accommodating to various needs and experiences.

In general, the generational identity of a person has a significant impact on attitudes toward new technologies and predetermines the degree of trust, enthusiasm, skepticism and resistance. It is due to this fact that the present study has integrated the generation gap as a moderating variable. It will seek to systematically investigate the role of generational differences on the readiness to embrace drone technology and offer critical information on the inter-generational aspects that play an important role in the adoption of novel food delivery solutions.

2.8. Research Framework

Figure 2 shows a Proposed TRAM model for the adoption intention of drone applications in food delivery services.

2.9. Hypotheses Development

Based on the discussion above, the following hypotheses were formulated to test the direct and indirect relationships between the constructs included in the model.

2.9.1. Direct Relationships

H1. *There is a significantly positive relationship between perceived usefulness and adoption intention.*

H2. *There is a significantly positive relationship between perceived ease of use and adoption intention.*

H3. *There is a significantly positive relationship between delivery risk and adoption intention.*

H4. *There is a significantly positive relationship between delivery risk and perceived usefulness.*

H5. *There is a significantly positive relationship between delivery risk and perceived ease of use.*

2.9.2. Mediating Relationships

H6. *The relationship between delivery risk and adoption intention is mediated by perceived usefulness.*

H7. *The relationship between delivery risk and adoption intention is mediated by perceived ease of use.*

2.9.3. Moderating Relationships

H8. *The relationship between perceived usefulness and adoption intention is moderated by the generation gap.*

H9. *The relationship between perceived ease of use and adoption intention is moderated by the generation gap.*

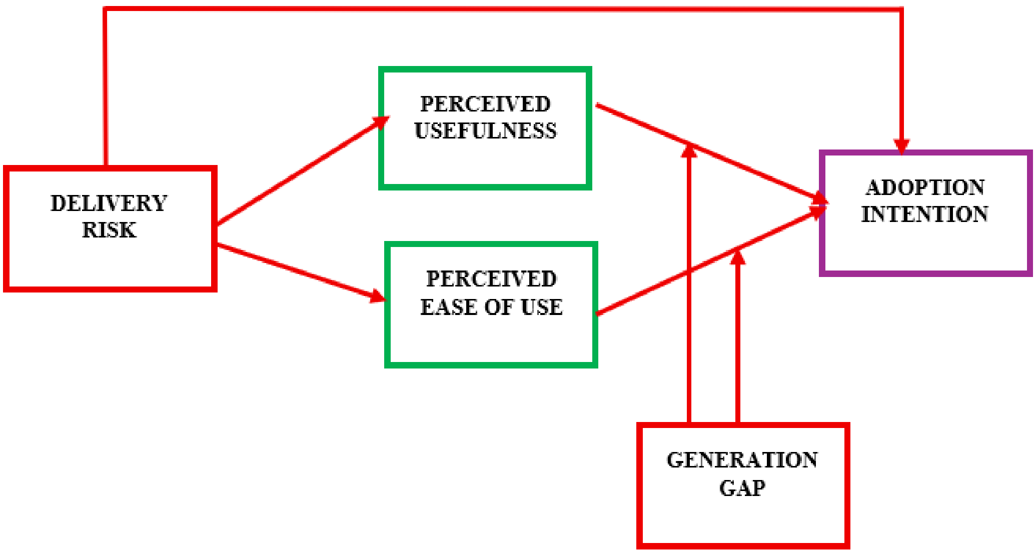

Figure 2. Proposal TRAM model for adoption intention on drones' application and usage in food delivery services.

3. Methodology

3.1. Research Design

Quantitative and qualitative research approaches were used in this research design of this study. This study adopted a quantitative cross-sectional data approach in the data collection process based on past studies.

Quantitative data is obtained through an online survey to accommodate COVID-19 pandemic restrictions. This assisted us in obtaining information relating to beliefs, attitudes, perceptions, or even opinions from other people in their natural environment. The online collection method is conducted through social media platforms such as WhatsApp, Facebook, and Instagram.

For the qualitative technique, telephone interviews and online focus group discussions with selected food delivery service providers and collaborators (Easyfly Autonomous Solution Sdn Bhd and Civil Aviation Authority of Malaysia) will be conducted.

3.2. Empirical Context

To measure delivery risk, three items were adopted from Lopez-Nicolas and Molina-Castillo [58], reflecting concerns about problems when delivering the product to a customer [9].

3.3. Research Method and Strategy

3.3.1. Sampling and Sample

This quantitative study targets customers as the unit of analysis. A multi-stage sampling method was conducted based on the generation gap and location. Generation was categorized into four groups: Baby Boomers, Gen X, Millennials (Gen Y), and Gen Z. The rationale behind selected generation gaps as a stratification factor was grounded in the observed differences in technology adoption levels among each generational cohort [59].

The sample size was doubled to accommodate a low response rate (**Table 1**). Thus, a sample size consisting of 384 or about 400 samples was needed in the study.

Table 1. Malaysian consumers population and sample size (Quantitative Method).

Generation\Location	Kuala Lumpur	Selangor	Johore	Penang	Total
Baby boomers	25	25	25	25	100
Gen X	25	25	25	25	100
Gen Y	25	25	25	25	100
Gen Z	25	25	25	25	100
Total sample size	100	100	100	100	400

3.3.2. Data Collection

For the quantitative method, a non-probability online survey method is used. Several studies have been conducted to validate the use of nonprobability sampling for online surveys. For this study, 800 questionnaires were distributed online using social media platforms such as WhatsApp, Facebook, and Instagram to Malaysian consumers in Kuala Lumpur, Selangor, Johor, and Penang.

For the qualitative method, the researchers conducted telephone interviews with 15 selected food service delivery providers in Malaysia. Also, telephone interviews were conducted with the Civil Aviation Authority of Malaysia (CAAM) and drone collaborator, Easyfly Autonomous Solution Sdn Bhd, to interrogate information regarding rules and regulations on drone aviation policy.

3.3.3. Data Analysis

To analyze the data, NVivo software was used for the qualitative component, while the Partial Least Squares (PLS) method was applied for the quantitative analysis. The quantitative analysis involved descriptive statistics using the Statistical Package for the Social Sciences (SPSS) version 20.0 and structural equation modeling (SEM) using SmartPLS version 3.2.7. Hypothesis testing was conducted with SmartPLS 3.2.7 to evaluate the predictive power of the independent variables—delivery risk—on the dependent variable, adoption intention. This analysis also considered the mediating roles of perceived usefulness and perceived ease of use, along with the moderating effect of the generation gap. The quantitative analysis addressed research objectives three through seven (RO3–RO7).

For the qualitative component, a verbatim analysis of interview transcripts was carried out using NVivo, with the aim of addressing research objectives one and two (RO1–RO2).

3.3.4. Validity and Reliability

Some tests were performed to confirm the reliability and validity of the main variables in the study. The variable of this study is adapted from relevant past studies (adoption intention of drone, perceived usefulness, perceived ease of use, and delivery risk). All measurements were tested to determine their reliability and suitability for the drone sector using factor analysis through a pilot study. All variables are measured using a 5-point Likert Scale from 1-strongly disagree to 5-strongly agree based on arguments from past studies. For the qualitative method, structured questions are designed to accommodate RQ1 and RQ2. Additionally, structured questions are developed to tap information from focus group discussions (FGD) with collaborators, such as Easyfly Autonomous Solution Sdn Bhd and the Civil Aviation Authority of Malaysia.

4. Results and Discussion

4.1. Assessment of the Measurement Model

Indicator item reliability was assessed by examining the outer loadings of each construct's individual measurement items [60–63] . According to Hair Jr. et al.[60], the recommended threshold for retaining items is between 0.40 and 0.70. Based on this criterion, 7 out of 67 items were removed due to loadings below 0.40. Consequently, 67 items were retained in the final model, with loads ranging from 0.501 to 0.951. A summary of these results is presented in **Table 2**.

Furthermore, internal consistency reliability refers to the extent to which all indicators within a particular (sub)scale consistently reflect the same underlying construct[64,65]. In organizational research, the most commonly used estimators for internal consistency are Cronbach's alpha and the composite reliability coefficient[66]. Despite ongoing debates regarding the most appropriate reliability metric, Cronbach's alpha remains widely used, although it may underestimate reliability [67,68]. However, in the context of PLS-SEM, composite reliability is considered more robust and is therefore preferred [69]. In this study, composite reliability was used to evaluate the internal consistency of the constructs.

Table 2. Indicator Loading, Internal Consistency Reliability and Convergent Validity.

Constructs	Items	Loading	CR	CA	AVE
Adoption intention	AI1	0.784	0.925	0.897	0.711
	AI2	0.793			
	AI3	0.887			
	AI4	0.878			
	AI5	0.867			
Delivery risk	DR1	0.772	0.892	0.873	0.547
	DR2	0.519			
	DR3	0.669			
	DR4	0.752			
	DR5	0.860			
	DR6	0.724			
	DR7	0.828			
Generation gap	GG1	0.698	0.877	0.825	0.590
	GG2	0.700			
	GG3	0.857			
	GG4	0.817			
	GG5	0.756			
Perceived ease use	PEU1	0.823	0.929	0.904	0.722
	PEU2	0.855			
	PEU3	0.847			
	PEU4	0.855			
	PEU5	0.869			
Perceived usefulness	PU1	0.828	0.923	0.894	0.705
	PU2	0.864			
	PU3	0.876			
	PU4	0.750			
	PU5	0.874			

As indicated in **Table 2**, the Average Variance Extracted (AVE) values range from 0.490 to 0.711, suggesting an acceptable level of convergent validity.

4.2. Assessment of the Structural Model

Once the measurement model was established, attention shifted to the structural model, which helps us understand how all the elements in the research framework connect and influence each other. Keeping up with recent advances in research methods, this study followed a two-step process for assessing and sharing the results from the PLS-SEM path analysis, as outlined by Henseler, Ringle, and Sinkovics [70].

To check if the links between variables were statistically significant, the structural model was examined using 1,000 bootstrap samples—a technique recommended by Hair Jr. and colleagues [62] and Henseler et al. [70]. For testing the proposed hypotheses, the research relied on partial least squares structural equation modeling (PLS-SEM), with data analysis done using SmartPLS version 3.3.3 [62].

4.3. Direct Relationship

This section presents the findings gathered before conducting the main mediation analysis by examining how variables relate to each other both directly and indirectly within the PLS structural model. When researchers talk about indirect effects, they're referring to the combined influence that flows through both direct connections and mediated pathways between two concepts, as Streukens and Leroi-Werelds [71] explain. Hayes and Preacher [72] put it another way: an indirect effect happens when an independent variable (X) influences a dependent variable (Y) by working through a mediating variable (M) that sits between them. In the context of PLS modeling, it is essential to report total effects prior to confirming mediation, as this offers a comprehensive view of the mediating construct's role and provides valuable insights for practitioners regarding the underlying cause-and-effect dynamics [62]. The results of the indirect effect analysis are presented in the following **Table 3.**

Table 3. Summary Direct Relationships.

Direct Relationships	Decision
H3. *Delivery risk has a positive and significant relationship with adoption intention.*	Not supported
H5. *Delivery risk has a positive and significant relationship with perceived ease of use.*	Not supported
H4. *Delivery risk has a positive and significant relationship with perceived usefulness.*	Not Supported
H2. *Perceived ease of use has a positive and significant relationship with adoption intention.*	Supported
H1. *Perceived usefulness has a positive and significant relationship with adoption intention.*	Supported

4.4. Mediation Results

This study used the PLS-SEM model through the means of bootstrapping analysis with formulated hypotheses to elaborate on the mediating effect [60]. This study confirmed the mediating role of perceived usefulness on the positive influence of delivery risk towards adoption intention; however, there is no mediation of perceived usefulness between delivery risk on adoption intention. **Table 4** below summaries the mediation results.

Moreover, perceived ease of use mediates positively between delivery risk with adoption intention in Smart PLS 3.0 [73] using the bootstrapping procedure with 5000 sub-samples and 400 cases. After including the mediator construct, satisfactions in the model, the bootstrapping result of 5000 samples.

4.5. Testing the Moderation Effect

The study was applied to test the strength of the moderation effect. **Table 5** details that no interaction of the moderation generation gap on perceived usefulness. Moreover, the generation gap does not moderate the relationship between perceived ease of use toward adoption intention was statistically not significant, indicating that the Generation Gap cannot enhance to achievement better higher intention for better adoption.

Table 4. Summary of Mediating Relationships.

Mediating Relationships	Decision
H6. *Perceived usefulness mediates the relationship between delivery risk and adoption intention.*	Supported
H7. *Perceived ease of use mediates the relationship between delivery risk and adoption intention.*	Not Supported

Table 5. Summary of Moderation Results.

Moderating Relationships	Decision
H8. *Generation gap moderates the relationship between perceived usefulness and adoption intention.*	Not supported
H9. *Generation gap moderates the relationship between perceived ease of use and adoption intention.*	Not supported

5. Discussion

5.1. The Secondary Role of Delivery Risk

Perhaps one of the most counter-intuitive findings from this research is the relatively weak direct influence of delivery risk on adoption intention. This suggests that when potential users evaluate a service like drone food delivery, their decision is not purely risk-averse. Instead, the evidence points to a practical trade-off where immediate, tangible benefits, namely speed, convenience, and efficiency. Those are weighed more heavily than probabilistic, abstract risks. This aligns with broader consumer behavior literature, which suggests that a technology's core utility is often the primary driver of adoption decisions [30,74].

The role of trust appears critical in this dynamic. The findings imply that trust acts as a foundational layer; as long as a baseline of confidence in the service provider is established, users seem willing to tolerate a degree of operational risk. In this view, risk doesn't disappear as a concern, but its power to deter adoption is significantly muted when trust is present [75]. It only becomes a primary barrier when that fundamental trust collapses.

5.2. Rethinking the Generation Gap in Technology Adoption

Another significant finding is the rejection of the hypothesis that generational differences moderate the powerful effect of perceived usefulness on adoption intention. In essence, the data shows that a drone's utility is just as persuasive for an older user as it is for a younger one. The appeal of a genuinely useful technology appears to be age-agnostic in this context.

Two main explanations for this emerge. First, the value proposition of drone delivery is exceptionally clear and practical. The benefit of receiving a meal quickly and efficiently is a universal one, not confined to the unique preferences of a single demographic. When a technology solves a common problem so effectively, its appeal can easily cut across generational lines. Second, we may be seeing evidence of the broader normalization of technology in society. As digital tools become ubiquitous, the once-stark 'digital divide' has arguably become more of a gentle slope. Older generations are increasingly comfortable with and reliant on new technologies, leading them to evaluate innovations like drones on their practical merits rather than approaching them with a strong generational bias.

This lack of a moderating effect helps explain the wider finding that the generation gap, on its own, was not a strong direct predictor of adoption intention. It appears that powerful universal factors like usefulness and social influence create a common ground for evaluation that can override age-based predispositions [76]. Of course, this relationship may be sensitive to context; cultural or regional factors could still produce different generational patterns in other settings [77]. Nevertheless, for this study, the practical usefulness of the technology was the dominant story. Future research should therefore be cautious about assuming generational differences and could instead explore other potential moderators, such as socioeconomic or cultural factors.

The Technology Readiness and Acceptance Model (TRAM) has proven especially useful for looking at how people might feel about using drones in food delivery services. What makes TRAM stand out is that it pulls together two key theories: TAM, which looks closely at users' opinions about specific technologies, and Technology Readiness (TR), which focuses more broadly on how open someone is to technology in general [20]. The Technology Readiness Index (TRI).

Results show that delivery risk had only a weak direct effect on adoption Intention. Within TRAM, this suggests that when delivery risk is present, individuals focus more on the perceived ease of use that mediates the relationship between delivery risk and adoption intention (e.g., speed, convenience, efficiency), reducing the weight of abstract risks [75].

This indicates that TRAM's contribution by showing that adoption is determined less by delivery risk and more by the combination of technology readiness and perceived utility, highlighting a mechanism where perceived ease of use transforms risk delivery into positive adoption intention.

6. Limitations and Implications

6.1. Managerial Implications

The findings from this study offer more than academic insight; they provide a strategic roadmap for successfully launching and managing drone delivery services in a competitive market like Malaysia. For managers and industry leaders, the key relationships uncovered between user perceptions and adoption intention translate into two critical imperatives:

First is engineer's trust in the service design. The significant impact of factors like delivery risk, discomfort, and insecurity reveals that user adoption is not just about technological capability but about psychological safety. Therefore, the first imperative is to move beyond mere functionality and actively engineer trust into the core user experience. This means implementing transparent, real-time tracking systems, establishing robust and responsive customer support for when issues arise, and designing an interface that is so intuitive (perceived ease of use) that it feels effortless and reliable. The goal is to create an ecosystem of reliability where the service's performance directly addresses and neutralizes user anxieties before they can become barriers to adoption.

Second, shaping the narrative with proactive communication. Therefore, it is for marketers to proactively shape the public narrative around drone delivery. This involves more than just advertising; it requires strategic communication aimed at building confidence. Campaigns should shift the focus from the novelty of the technology to its tangible benefits and reliability. By transparently showcasing safety protocols, operational efficiency (perceived usefulness), and positive user testimonials, companies can build a narrative of trust and competence, appealing to both enthusiastic innovators and more cautious potential users alike.

In the fast-paced food delivery industry, success will demand dynamic vigilance. Managers must continuously monitor consumer sentiment and be agile enough to adapt their service and messaging, ensuring they not only meet but exceed user expectations to drive lasting adoption.

6.2. Limitations and future studies

This study recognizes certain limitations in its representation of the adoption process for the drone application and usage intention model in food delivery services, particularly due to the potential insufficiency of the integrated external factors. Future research could expand the model by incorporating additional variables such as risk perception, mobile self-efficacy, perceived anxiety, and perceived image, thereby offering a more holistic understanding of the adoption process.

Moreover, future studies could consider including a broader range of demographic variables, such as individual cultural values, prior experience, education level, and income. These factors may offer deeper insights into the diverse influences on technology adoption behavior.

Another limitation of the current model is the exclusion of actual usage behavior. Future research should examine the relationship between behavioral intention and actual usage to assess how effectively intentions lead to real-world adoption of drone-based food delivery technologies.

Lastly, the cross-sectional nature of this study restricts its ability to observe changes in user perceptions over time. Adopting a longitudinal approach in future research could shed light on how adoption-related attitudes and behaviors develop and change across different time periods.

7. Conclusions

The study extends the Technology Acceptance Model (TAM) by incorporating additional parameters such as social influence, trust, and security/privacy into the model. These parameters are found to be empirically influential in the decision-making process of adopting drones in delivery service technologies by consumers, particularly patients. The TAM model is found to apply to the domain of service delivery in a developing country like Malaysia. This suggests that the foundational constructs of TAM, such as Perceived Ease of Use (PEOU) and Perceived Usefulness (PU), remain relevant even in unique contexts such as drone application and usage in food delivery services in developing countries.

The study finds that cost perception is not a significant factor in the acceptance of technology among customers in Malaysia. This underscores the need for a deeper understanding of the factors influencing technology adoption in specific cultural and socioeconomic contexts. The study identifies age and gender as moderators that have empirical significance in the adoption of technology. This suggests that demographic factors may interact with the core constructs of TAM in influencing technology adoption behaviors.

Author Contributions

All authors contributed equally to the conception, design, data collection, analysis, and writing of this study. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

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Not applicable.

Data Availability Statement

The data used in this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

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